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Nationwide Urban Runoff Program
The Piscataway Creek Watershed Study
Final Report

Metropolitan Washington Council of Governments
DC

Prepared for

Environmental Protection Agency, Washington, DC

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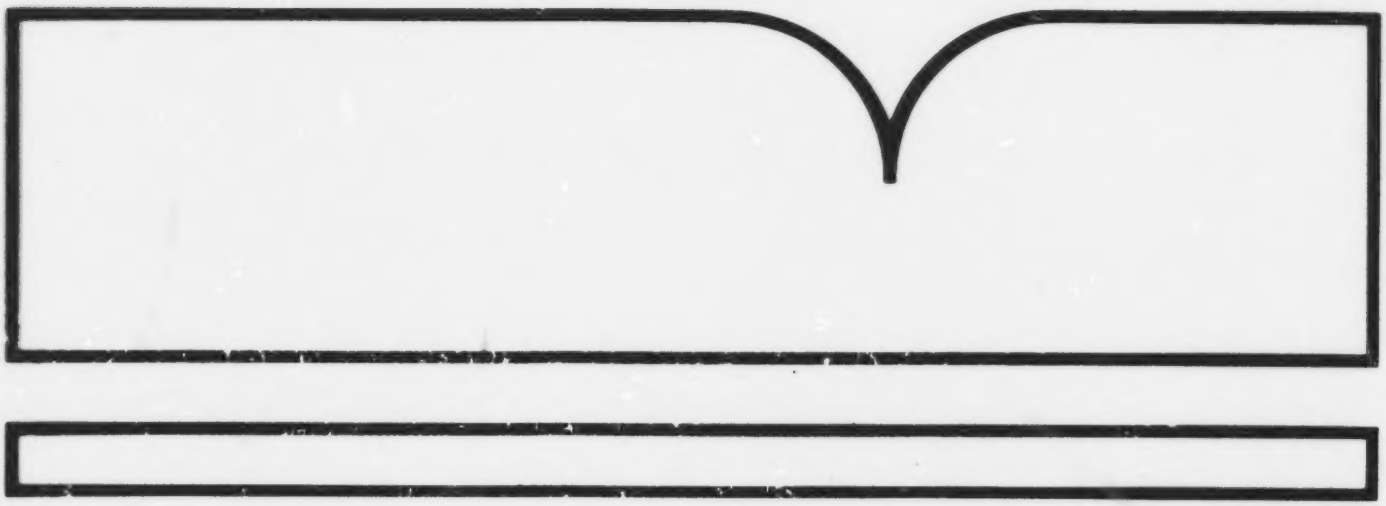

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THE PISCATAWAY CREEK WATERSHED STUDY

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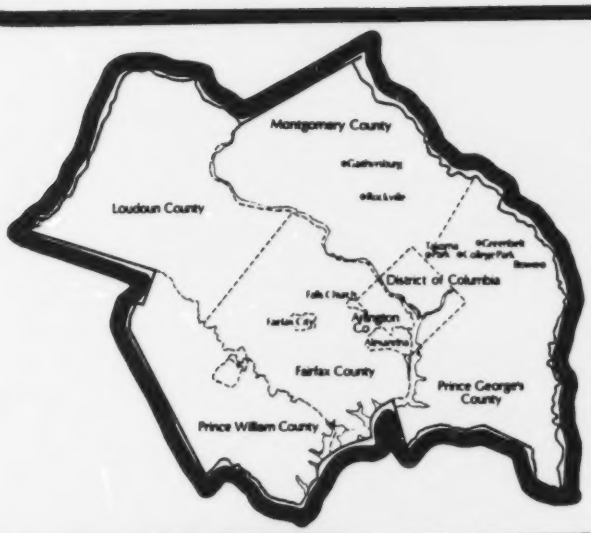

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This study involved the application of a calibrated watershed model to project hydrologic, water quality and sediment changes expected to occur with future development of the Piscataway watershed, both with and without controls to determine environmental impacts. The study concludes with a recommended management program.

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FINAL REPORT

September, 1983

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prepared for

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TABLE OF CONTENTS

	Page
LIST OF FIGURES	iii
LIST OF TABLES	v
EXECUTIVE SUMMARY	vii
CHAPTER 1. EXISTING CONDITIONS	1
Study Overview	1
Description of the Watershed	2
Wildlife and Recreation Resources	4
Current Water Quality Conditions	5
CHAPTER 2. THE WATERSHED MODEL - PROCESSES AND APPLICATION	7
Water Quality: Land Processes	7
Water Quality: Instream Processes	8
Sediment: Land Processes	10
Sediment: Instream Processes	11
Flow and Water Quality Data	11
Subwatersheds and Channel Reaches	12
Land Use	16
Other Model Inputs	16
The Calibration Process	19
CHAPTER 3. RESULTS OF MODEL CALIBRATION	21
Hydrology	21
Dissolved Oxygen/BOD	24
Nutrients	26
Sediment	30
Summary of Calibration Results	32
CHAPTER 4. MODEL PROJECTIONS AND IMPACTS	33
Hydrology	33
Dissolved Oxygen/BOD	35
Nutrients	35
Sediment	37
Summary of Model Projections and Impacts	38

CHAPTER 5. MANAGEMENT OF STORMWATER AND NONPOINT POLLUTANTS IN THE PISCATAWAY WATERSHED..... 41

Wet Ponds as a BMP Strategy..... 42
Other Best Management Practices..... 50
Summary of Management Practices..... 55

CHAPTER 6. RECOMMENDED MANAGEMENT PLAN..... 57

Recommended Management Practices..... 57

REFERENCES

APPENDIX A: EXISTING AND PLANNED LAND USE IN SUBWATERSHEDS OF PISCATAWAY CREEK

APPENDIX B: ANNOTATED WATERSHED MODEL INPUT STREAM

LIST OF FIGURES

FIGURE		PAGE
1.1	Map of Piscataway Watershed.....	3
2.1	Channel Reaches and Subwatersheds of Piscataway Creek.....	13
3.1	Comparison of Simulated and Observed Annual Runoff in Piscataway Creek.....	22
3.2	Simulated and Observed Flow Duration Curve.....	22
3.3	Piscataway Creek Storm Event of February 2-3, 1983.....	23
3.4	Comparison of Observed and Simulated Runoff in Inches.....	23
3.5	Comparison of Simulated and Observed Dissolved Oyxgen Concentrations.....	25
3.6	Comparison of Simulated and Observed Individual Storm Ammonia Loads.....	25
3.7	Comparison of Observed and Simulated Cumulative Storm Loads.....	27
3.8	Comparison of Observed and Simulated Cumulative Loads - Baseflow and Stormflow Periods.....	27
3.9	Comparison of Simulated and Observed Individual Storm Nitrate Loads.....	29
3.10	Comparison of Simulated and Observed Individual Storm Total Organic Nitrogen Loads.....	29
3.11	Comparison of Simulated and Observed Individual Storm Total Phosphorus Loads.....	31
3.12	Comparison of Simulated and Observed Individual Storm Sediment Yields.....	31
4.1	Comparison of Sediment Frequency At or Above 100 mg/l.....	39
4.2	Comparison of Average Annual Peak Sediment Concentrations by Reach.....	39
5.1	Comparative Performance of Wet and Dry Stormwater Management Ponds in the Washington Area NURP Project.....	51

5.2 Comparative Pollutant Removal Performance of Porous Pavement and Infiltration Pits..... 53

LIST OF TABLES

Table		Page
2.1	Subwatersheds of Piscataway Creek.....	14
2.2	Geometric Properties of Idealized Channel Reaches.....	15
2.3	Existing and Planned Land Use in Piscataway Watershed.....	17
4.1	Model Projections: Existing and Future Development Under Average Annual Meteorological Conditions.....	34
5.1	Summary of Projected Piscataway Loads.....	44
5.2	Storage and Cost Estimates for Off-site Wet Ponds.....	48

FINAL REPORT ON PISCATAWAY CREEK STUDY

EXECUTIVE SUMMARY

A calibrated watershed model was applied to project hydrologic, water quality and sediment changes that would be expected to accompany future development in the Piscataway watershed. The projections were based upon a "planned" land use situation under consideration by the Maryland-National Capital Park and Planning Commission. Without the concurrent implementation of appropriate runoff controls, adverse environmental impacts were projected including increases in stormwater, nutrient and sediment loads, and streambank erosion. The ability of nonpoint source controls, or Best Management Practices (BMPs), to provide protection for the stream and to minimize the adverse consequences associated with future development upon water quality and instream habitat was also examined. The approximate cost of a widespread application of BMPs is presented. A discussion of the effectiveness of various control practices and their suitability for application in Piscataway Creek is also presented. And finally, a recommended management program is set forth.

The principal conclusions from this study, including previous reports, are as follows:

CURRENT ASSESSMENT OF ENVIRONMENTAL CONDITIONS AND WATER QUALITY

- The Piscataway Watershed encompasses extensive areas of forest and wetland habitat that supports a rich diversity of aquatic and terrestrial life.

- There do not appear to be any dissolved oxygen or euthrophication problems in the free flowing poriton of Piscataway Creek.

- Violations of state water quality standards for fecal coliform, turbidity and pH are common.

- High concentrations of suspended sediment occur regularly during storms. Both streambank erosion and sedimentation are currently causing impairment of the instream habitat and its ability to support a diverse community of aquatic life.

- Several trace metals occasionally exceed water quality criteria established by EPA for the protection of aquatic life and human health.

- Nutrient loads originating within the watershed contribute to the enrichment of tidal waters in Piscataway embayment and the Upper Potomac estuary.

- There is some evidence within the sediment and water quality data, as well as some visual evidence along the Creek itself, that the ability of the watershed to continue supporting a highly diverse aquatic community is threatened.

THE PISCATAWAY WATERSHED MODEL AND MODEL PROJECTIONS

- The ability of the watershed model to simulate the principal processes affecting basin hydrology, the generation and transport of nonpoint source pollutants and sediment, and instream water quality was demonstrated.

- Model projections based on a "planned" future land use situation showed that stormwater, nutrient and sediment loads would increase substantially in the absence of appropriate urban runoff control measures.

- Basin hydrology was projected to change significantly due to development and increased impervious cover. An increase in peak runoff rates, less infiltration and recharge of groundwater, and longer more frequent periods of zero flow could be expected.

- Stream bank erosion and channel scour was projected to increase dramatically unless controlled.

- As projected, future water quality in Piscataway Creek would principally be affected by increased turbidity and lower water clarity. The tidal receiving waters of Piscataway embayment and the Upper Potomac estuary were projected to receive larger annual loads of sediment and nutrients which would contribute to existing problems related to eutrophication and the loss of submerged aquatic vegetation.

RECOMMENDED MANAGEMENT PRACTICES

- Increases in stormwater volume and associated sediment loads pose the biggest threat to water quality in the watershed. Every effort should be made to put controls in place that would maintain runoff volume and flow rates at predevelopment levels.

- The flood control alternatives under consideration by the Stormwater Management Technical Committee would probably have a negligible impact on reducing nonpoint source pollutant loads and the generation of sediment within the watershed.

- A large degree of control over the increases in loads projected under the "planned" land use situation ranging from nearly 100 percent for some nutrients to approximately 75 percent for sediment would be possible with the widespread application of Best Management Practices.

- Management practices such as the use of wet ponds, extended detention dry ponds, porous pavement, or other well-designed infiltration controls could be implemented to provide flood control protection in addition to erosion control and other water quality benefits. The use of these measures would also provide for high levels of nutrient removal from runoff which would assist in the abatement of accelerated eutrophication in the Piscataway embayment and the Upper Potomac estuary.

- Piscataway Creek represents a valuable wildlife resource for both freshwater and anadromous fish. The future protection of this resource is dependent upon the implementation of appropriate management practices to control the increases in stormwater runoff and pollutant generation projected to accompany increased development in the watershed.

CHAPTER 1. EXISTING CONDITIONS

STUDY OVERVIEW

The Piscataway Creek Study was undertaken by the Metropolitan Washington Council of Governments(COG) to investigate water quality and to identify stormwater and nonpoint source management needs within the Watershed. The study is intended to demonstrate how an assessment of nonpoint pollution problems and abatement strategies at the watershed level can be integrated as part of ongoing land use and stormwater management activities. The study includes an extensive water quality data collection effort, a detailed report on the current status of water quality and water quality trends within Piscataway Creek, and the development and application of a prototype watershed model. The watershed model is designed to be used as a water resources planning tool for the evaluation of land use planning alternatives and applied management practices, and for the assessment of their impacts upon stormwater runoff and water quality.

This report describes how the watershed model was applied to simulate the accumulation, washoff and transport of sediment and water quality constituents within the Piscataway drainage. A full discussion of the model's calibration that describes the evaluation and refinement of rates and parameters according to observed data is presented. Likewise, a complete description of model inputs and calibrated rates and parameters is included. These serve as documentation of the model calibration and application. A strong case for using the watershed model as a stormwater and nonpoint source management tool is made.

The results of applying the model to existing and planned (future) land use patterns are also presented. Changes in sediment and pollutant loadings projected to occur due to development are shown. The ability of nonpoint source controls to reduce projected increases in urban stormwater loads is demonstrated, and recommendations for a sediment and nonpoint source management strategy are presented.

The study has been conducted in coordination with Prince George's County Regional Office of the Maryland-National Capital Park and Planning Commission (M-NCPPC). Previous COG reports developed as part of this study dealt with an initial assessment of future nonpoint loading conditions in Piscataway Creek (MWCOG, 1981) and a documentation report on the calibration of the Piscataway Watershed Model to basin hydrology (MWCOG, 1982). In addition, a detailed assessment of current water quality conditions and recent trends within Piscataway Creek was conducted (MWCOG, April 1983).

Funds for this project were provided as part of an overall research grant to COG from the U.S. Environmental Protection Agency under the Nationwide Urban Runoff Program (NURP). This document represents COG's final report on the Piscataway Creek portion of its NURP studies for EPA.

DESCRIPTION OF THE WATERSHED

The Piscataway watershed is located in the southwestern portion of Prince George's County, Maryland as shown on Figure 1.1. The watershed, including adjacent Tinker's Creek, encompasses an area of 60 square miles, and it drains to the Piscataway embayment, a tidal appendage of the Potomac estuary. Piscataway Creek occupies a well-defined valley, with elevations ranging from sea level to 250' above sea level. Gemorphologically, the watershed lies within the Atlantic Coastal Plain Province. Soils are principally sandy loams and silt loams derived from the underlying sedimentary materials. The climate is decidedly humid and temperate, with average precipitation on the order of 40 inches per year.

Current land usage in the watershed as provided by M-NCPPC during 1982 is as follows: residential and commercial development occupy approximately 15 percent of the area; pasture and row crops occupy another 15 percent; and the remainder is principally forest, with some areas of open unforested land. With the exception of a portion of Andrews Air Force Base that occupies the northern border of the watershed, and a few scattered pockets of development, the watershed is

FIGURE 1.1

PISCATAWAY CREEK

Source: M-NCPPC

generally rural in character. However, due to its proximity to the urban core and the suburban fringe of the Washington Metropolitan Area, a great deal of new residential and commercial development is expected to occur within the watershed over the next twenty years.

WILDLIFE AND RECREATION RESOURCES

The Piscataway watershed contains a very rich variety of terrestrial and aquatic habitat. Much of the watershed is currently covered with extensive areas of forest and wetlands, particularly in the stream valley. The Creek itself drains through the relatively undeveloped valley bottom to a large tidal freshwater marsh near its mouth, which represents the head of the Piscataway embayment.

The existing situation within the watershed provides sufficient food, cover and breeding/spawning grounds for the support of a wide variety of plant and animal life. One report of the identification of 41 fish species in Piscataway Creek is referenced in a "Technical Data Base Study" of Piscataway Creek (P.G. County, 1981). Other recent surveys and reports that quantify the value and diversity of wildlife resources within the watershed include a "Survey of Anadramous Fish Spawing Areas for the Potomac River and Upper Chesapeake Bay Drainage" (MD DNR, 1975), a "Preliminary Investigation of the Piscataway Creek Watershed" (SCS, 1978), and a "Baseline Inventory of Wetlands in Piscataway Creek and the Adjacent Potomac River" (Ecological Analysts, Inc., 1978).

Recognition of the value of the Piscataway watershed as an important area of wildlife habitat, and the threat to this resource posed by the encroachment of development, has been made by several public agencies. The Smithsonian Institute rated an area of the watershed near Windbrook Drive as "high in wildlife value" and listed it as an "ecologically valuable area" (Smithsonian Institute, 1974). In addition, the Maryland Departmentof State Planning designated the 100-year floodplain, tidal wetlands and non-tidal wetlands of Piscataway Creek as "Areas of Critical State Concern" (MD DSP, 1981).

In terms of recreation the watershed contains several regional parks as well as numerous neighborhood parks, playgrounds and recreation areas, most of which are administered and operated by the Maryland-National Capital Park and Planning Commission. Further detail on recreation resources is provided in the above mentioned SCS report.

CURRENT WATER QUALITY CONDITIONS

The previously mentioned assessment of water quality in Piscataway Creek (MWCOG, April 1982) examined a wide variety of physical, chemical and biological parameters. Several of the principal conclusions are presented below, with further detail provided in the assessment report itself.

Nutrients and BOD from nonpoint sources did not appear to be causing any serious water quality problems within free-flowing sections of Piscataway Creek. Dissolved oxygen concentrations remained close to saturation and above the Maryland standard of 5.0 mg/l at all times. Fecal coliform concentrations, however, were frequently in violation of state standards, especially during storms. Low values of pH were also common, with half of the observations below the state minimum standard.

In regard to sediment, concentrations between 100 and 1000 mg/l during storm flow periods were found to persist for durations well in excess of 24 hours. Evidence of streambank erosion and sedimentation were observed to be commonplace along the mainstem of Piscataway Creek. These sediment conditions were thought to be causing impairment of the instream aquatic habitat.

Several toxic constituents including iron, manganese, zinc, copper and nickle concentrations occasionally exceeded water quality criteria established by EPA for the protection of human health and aquatic life.

Although Piscataway Creek has a good oxygen balance and no apparent nutrient enrichment problems, it does have pollution problems, the most serious of which are related to sediment.

CHAPTER 2.
THE WATERSHED MODEL: PROCESSES AND APPLICATION

The Piscataway Watershed model represents an application of the Hydrologic Simulation Program Fortran (HSPF) model (Hydrocomp, 1980). HSPF is a continuous simulation model that is capable of simulating most of the major physical, chemical and biological processes affecting stream flow and water quality that occur within a watershed in a very comprehensive manner. As mentioned, the hydrologic portion of the model has been calibrated and verified, and the ability of the model to generate surface runoff, interflow and baseflow, and to transport these runoff components through an idealized channel system, was demonstrated (MWCOG, 1982). Further discussion of model calibration results is presented in Chapter 3. The intent of this chapter of the report is to describe the sediment and water quality processes simulated in this model application, and to provide documentation on the technical approach and data required for the calibration of the sediment and water quality aspects of the model.

WATER QUALITY: LAND PROCESSES

The water quality constituents simulated as nonpoint source pollutants in this model application are ammonia, nitrate, total organic nitrogen, total phosphorus, and BOD. Sediment is also modeled, but it is discussed separately in the following section. In pervious (soil cover) land areas these water quality constituents can be conveyed to stream channels along several pathways. On the surface, constituents accumulate over time and are subject to being washed off with overland flow. To a certain extent this represents the delivery and contribution of atmospheric loading sources. Another surface pathway is available for those constituents closely associated with sediment. Sediment particles that become detached due to rainsplash or scour and transported to streams with overland flow are represented by a fixed percentage or "potency" for individual constituents. Beneath the land surface, concentrations of a constituent are assigned to interflow and baseflow, the two avenues of subsurface flow.

On impervious surfaces, the first two pathways associated with overland flow and sediment washoff are simulated in roughly the same manner as done for pervious areas. However, there are no subsurface pathways beneath impervious covers.

To account for inherent differences in pollutant accumulation rates related to land use and seasonal factors, many of the rates and parameters in the model input can vary from month-to-month and from one constituent to another. Similarly, the relative importance of the various pathways is determined by the way in which each is defined in the model input. This flexibility allows for a great deal of detail and specificity in describing the generation of nonpoint pollutants.

WATER QUALITY: INSTREAM PROCESSES

Constituents are transported through the watershed within the channel system described in the model input. Complete mixing is assumed for each channel segment. The principal processes affecting the constituents being simulated are advection, settling, aeration, and other chemical and biochemical reactions such as nitrification and BOD decay. Within the model, the presence or absence of these processes and the rates at which they occur govern the amount of a given constituent that passes through the watershed and its concentration at any given time. The specific processes affecting each of the constituents or constituent groups being simulated are summarized below.

Dissolved Oxygen - BOD

Several important factors control the oxygen balance within a given channel segment. One is water temperature, which in this application is a model input that determines the saturation dissolved oxygen concentration. Another factor is the amount of oxygen supplied through aeration, which is rather dependent on flow velocity, bottom roughness, and channel slope. Inflow concentrations of dissolved oxygen from upstream channel segments and the amount of dissolved oxygen in surface runoff, interflow and baseflow are also very influential. Likewise, the amount of BOD present is also important as BOD decay, a

reaction based on first-order temperature kinetics, causes some depletion of the available supply of dissolved oxygen. The BOD concentration itself is a function of inflow concentrations and the rate at which BOD is reduced by decay and settling. During and following storm events the BOD load delivered to the channel system from surface washoff can be very large. However, its influence on dissolved oxygen within Piscataway Creek is limited by its brief residence time since the BOD is typically transported out of the watershed within a day's time, and thus its full effect over a longer period is not felt within the channel system.

Ammonia, Nitrite and Nitrate

These three forms of nitrogen, ammonia (NH3), nitrite (NO2) and nitrate (NO3), are closely interrelated and are thus simulated in HSPF in a similar manner. Ammonia and nitrate loads are delivered to a given channel segment from upstream sources, surface washoff, and subsurface flows. In addition to longitudinal advection, ammonia vaporization and nitrification are the principal processes at work. Ammonia vaporization represents a direct loss of ammonia to the atmosphere. The nitrification process accounts for the oxidation of ammonia to nitrite and finally to nitrate. Both of these reactions are temperature dependent, and the rates at which they occur increase with increasing water temperature. In reality neither of these processes is particularly important in Piscataway Creek as the amount of ammonia lost due to either vaporization or nitrification is very small and never exceeds 15% per day.

Conservatives

Two nonpoint source constituents, total organic nitrogen and total phosphorus, were simulated as conservative substances that, once generated, do not undergo further change within the watershed. The concentrations of both are strongly related to storm runoff, with high concentrations of very typical during storms. These constituents were treated as conservatives in this analysis because the large storm loads pass so quickly through the watershed that low levels of degra-

dation or transformation would be expected. As modeled, the only instream process affecting these constituents is longitudinal advection.

SEDIMENT: LAND PROCESS

The generation of sediment from pervious surfaces is the result of two processes that are modeled separately. In the first, a time varying balance of detached sediment particles is maintained. Sediment is added to the pool of detached particles by rainsplash, which is chiefly determined by rainfall intensity, the extent of vegatative cover, and the erodibility of the soil matrix. The deposition of sediment directly from the atmosphere also contributes to the pool of detached particles. Reattachment of sediment particles to the soil matrix at a constant rate during nonstorm periods, however, provides a loss mechanism or means by which the pool of detached particles is kept in check. The washoff of sediment from the detached sediment pool is accomplished with a transport algorithm based on the amount of runoff generated, transport capacity, the amount of detached sediment available, and the length, slope and roughness of the overland flow plane.

In a separate calculation, scour of sediment directly from the unlimited supply of sediment within the soil matrix is simulated. This process represents rill and gully erosion, and it is based upon the generation of surface runoff and a scour algorithm.

On impervious surfaces, there is no detachment of sediment from rainsplash or scour since there is no soil matrix. However, a net accumulation of sediment or solids due to atmospheric deposition and other human activities is simulated. The washoff of this pool of detached particles is accomplished within a sediment transport algorithm based upon the generation of surface runoff, and the characteristics of the overland flow plane.

Sediment that is washed off or eroded from pervious or impervious surfaces is partitioned into fractions of clay, silt and sand as it is

delivered to a stream channel. These fractions were assigned on the basis of sediment size distributions in runoff from studies in the Metropolitan Washington Area.

SEDIMENT: INSTREAM PROCESSES

The three sediment size fractions - clay, silt and sand, are treated independently in the channel system. Individual fractions are conveyed through a channel segment and maintained in suspension subject to adjustment for deposition due to settling and additions due to channel scour. The sediment dynamics algorithm simulates the exchange of each fraction between channel (bed) storage and suspended storage, and vice versa. If the hydrodynamic conditions within a channel segment are not sufficient to carry the entire suspended sediment load, the suspended sediment gradually enters into channel storage at a rate governed by the settling rates of each size fraction and a critical threshold level related to velocity and bed shear stress. When hydrodynamic conditions within a channel segment are more than sufficient to carry the suspended load, sediment within channel storage may be scoured and resuspended. This flux is triggered when velocity reaches a point where bed shear stress is raised above a critical threshold level.

The sum of all three of the sediment size fractions at any time represents the total suspended sediment load in a given channel segment.

FLOW AND WATER QUALITY DATA

Observed flow and water quality data were essential to the water quality model calibration in which observed and simulated values were compared directly. In this application, mean daily flow values and individual storm hydrographs were available at the U.S. Geological Survey (USGS) gaging station at Piscataway, Maryland. As part of the NURP study, an automated water quality sampler was also installed at the USGS gaging station. The sampler configuration and operation was designed for the collection of volume weighted samples during storms,

with the sampler triggering on and off at a critical stage on the rising and falling limb of the hydrograph. Storm durations were variable ranging from eight hours to several days. During the seventeen month monitoring period, thirty of the volume-weighted storm samples were collected. In addition, forty-five baseflow grab samples were collected during field visits to augment the storm samples. A wide variety of water quality constituents were analysed including total suspended sediment, particulate and dissolved forms of nitrogen and phosphorus, DO/BOD, trace metals, and various forms of bacteria.

Unfortunately, the monitoring period coincided with a prolonged drought over the watershed. As an example, average flow at the Piscataway gage during the seventeen month NURP sampling period was only 11 cubic feet per second (cfs) in contrast to the average flow of 47 cfs over the seventeen year period of record. The flows during the sampling period were only 25 percent of normal. Nonpoint source constituent concentrations and loads were similarly affected by the unusually dry conditions. It is felt that total observed loadings, and in some cases concentrations, would have been considerably higher if meteorological conditions during the NURP sampling period had been more normal.

SUBWATERSHEDS AND CHANNEL REACHES

The area explicitly modeled with HSPF was the 39.5 square mile drainage above the Geological Survey stream gage at Piscataway, Maryland near Piscataway Road (Route 223). The watershed above this point was divided into fourteen subwatersheds that generally corresponded to tributaries or groups of small tributaries. These subwatersheds are identified on Figure 2.1 with their drainage areas identified on Table 2.1.

The main channel of Piscataway Creek draining these subwatersheds was represented by a network of seven channel reaches. These channel reaches are also shown on Figure 2.1, and they extend from the headwaters near Andrews AFB to the USGS stream gage. The geometric properties of each idealized channel reach are presented in Table 2.2.

FIGURE 2.1. CHANNEL REACHES AND SUBWATERSHEDS OF PISCATAWAY CREEK

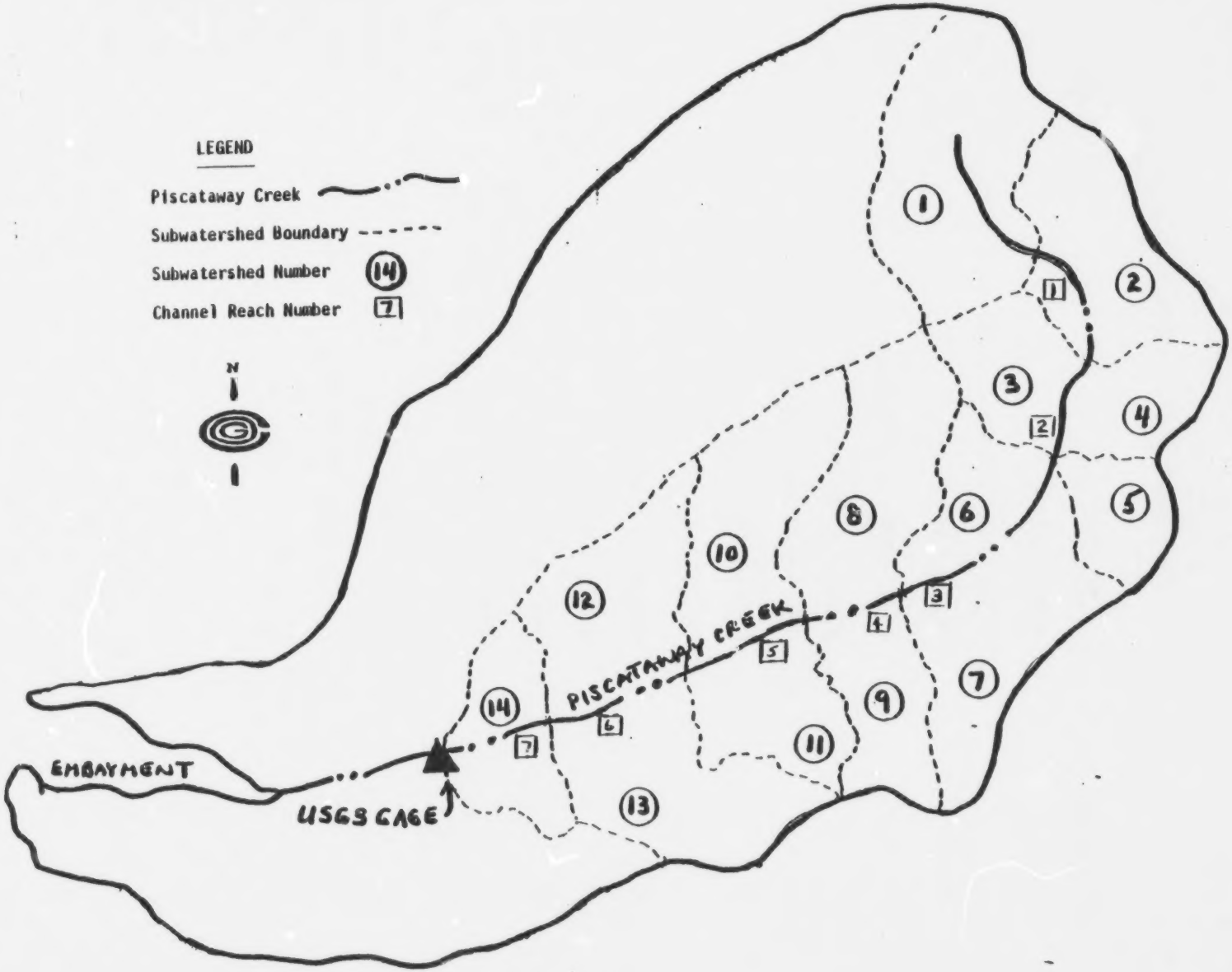


TABLE 2.1 SUBWATERSHEDS OF PISCATAWAY CREEK

SUBWATERSHED	DESCRIPTION	AREA (sq.mi)
1	Andres AFB	3.7
2	Coles Corner/Woodyard Area	1.4
3	Unnamed Tributary	0.8
4	Dower House Pond Branch	1.0
5	Unnamed Tributary	3.2
6	U.S. Naval Reservation	2.4
7	Boys Village Area	2.9
8	Piney Branch	4.6
9	Unnamed Tributary (Rt. 5)	2.5
10	Butler Branch	5.5
11	Blandford Village	1.8
12	Unnamed Tributary	3.0
13	Burch Branch	4.6
14	Unnamed Tributary	2.2
	TOTAL AREA	39.6

TABLE 2.2. GEOMETRIC PROPERTIES OF IDEALIZED CHANNEL REACHES

REACH #	LENGTH (MI)	ELUP* (FT)	ELDOWN* (FT)	WIDTH OF CHAN BOT (FT)	WIDTH OF CHAN TOP (FT)	DEPTH OF CHANNEL (FT)	MANNINGS 'N' CHANNEL	MANNINGS 'N' FL'PLAIN
1	2.1	200	173	10	14	3.0	.047	.15
2	1.7	173	153	14	20	3.0	.047	.15
3	3.9	153	106	20	28	3.0	.047	.15
4	2.4	106	85	25	34	3.4	.047	.15
5	4.2	85	55	34	35	3.0	.047	.15
6	3.4	55	38	33	41	3.3	.047	.15
7	3.0	38	11	31	43	3.5	.047	.15

*
ELUP = ELEVATION AT THE UPSTREAM END OF THE REACH
ELDOWN = ELEVATION AT THE DOWNSTREAM END OF THE REACH

LAND USE

A comprehensive inventory of land use data for the Piscataway watershed was provided by M-NCPPC. This information is summarized in Table 2.3. The number of acres in each of the land use categories is given for the existing land use situation as well as for the "planned" land use situation. The latter represents nearly full development of the watershed at an unspecified time in the future. More specific information on the distribution of existing and planned land use within the subwatersheds is contained in Appendix A of this report.

In applying the model to the watershed, the land use data was aggregated into four pervious segments that were modeled separately to account for inherent differences in hydrologic and pollutant generation rates. These were forest, a combined pasture and row crop category, open-unforested land, and a developed residential/commercial category. In addition, all of the imperviousness associated with any given land use within the watershed was aggregated together and modeled as a single land use type.

OTHER MODEL INPUTS

Application of the HSPF watershed model also required other time series and environmental inputs. These are summarized by category below:

Hydrologic Inputs

The previously mentioned report on the Hydrologic Calibration (MWCOG, 1982) presents a complete discussion of hydrologic inputs. These same hydrologic inputs were used in the water quality application. Additional information for specific rates or parameters is provided in the Annotated Input Listing for the watershed model in Appendix B of this report.

TABLE 2.3 EXISTING AND PLANNED LAND USE IN PISCATAWAY WATERSHED

LAND USE #	M-NCPPC LAND USE CATEGORY	IMPERVI-OUSNESS	ZONING CATEGORY	EXISTING ACREAGE	PLANNED ACREAGE
111	RESIDENTIAL 0-1 DU/ACRE	6%	RE	645	11,575
112	RESIDENTIAL 1-2 DU/ACRE	12%	RR	641	6,844
113	RESIDENTIAL 2-4 DU/ACRE	20%	R 80	692	1,167
114	RESIDENTIAL 4-6 DU/ACRE	35%	R 55	841	1,633
115	RESIDENTIAL >6 DU/ACRE.	35%	OTHER RESIDENTIAL	16	16
12	COMMERCIAL	90%	ALL COMMERCIAL ZONES	4	137
13	INDUSTRIAL	60%	ALL INDUSTRIAL ZONES	1832	2,300
14	EXTRACTIVE	60%	NA	0	0
15	TRANSPORTATION, UTILITIES	60%	NA	220	198
16	INSTITUTIONAL	35%	NA	0	0
191 and 192	OPEN	5%	NA	4610	1,221
21 and 22	CROPLAND AND PASTURE	1%	NA	3400	6
41 and 42	FORESTS	1%	NA	12341	145
	TOTAL AREA			25242	25,242

Source: Maryland-National Park and Planning Commission, Prince George's County.

Water Quality Inputs

A great deal of specific local information on land use/runoff quality relationships (NVPDC and VPI&SU, 1978) and nonpoint pollution loading factors (Hartigan, et al, 1982) was drawn upon in this portion of the model application. A complete set of the rates, constants, parameters and other model inputs used in this application is provided in the annotated model input listing contained in Appendix B.

Meteorological Data

The hourly precipitation record observed at National Airport was used as the basis for the meteorological input for the water quality calibration effort. This record was available for the entire seventeen month period in which water quality sampling was active. A recording raingage was also installed at the Louise Cosca Regional Park within the Piscataway watershed. However, due to operational problems this gage only provided a partial intermittent record which was used as a supplement to the National Airport record. Additional resolution of the rainfall pattern over Piscataway was obtained through the use of local isohyetal maps for individual storms prepared as part of the Metropolitan Climatological Summaries (NWS, 1980,81). These maps proved to be very helpful. The result of utilizing these three sources was an hourly record of mean areal precipitation for the Piscataway Creek watershed.

Potential evapotranspiration (PE) data was not monitored within the watershed during the study. A representative daily PE record was created by averaging the nine-year PE record that was used in the hydrology calibration and verification.

Water Temperature

A continuous hourly record of water temperature was required as model input because many of the water quality reactions are temperature dependent. The occasional weekly or less frequent measurements available in the Piscataway watershed were not nearly sufficient

enough to describe instream water temperatures over time. Therefore, a substitute record was required and the observed water temperature record from Seneca Creek in Montgomery County was borrowed. It was thought that the Seneca Creek water temperature conditions would be roughly similar to water temperature conditions in Piscataway Creek. It was also thought that the Seneca Creek record would provide a reasonable approximation of day-to-day and diurnal changes within the Creek because water temperature in the two streams is principally governed by atmospheric temperature and the temperature of groundwater. These two environmental factors do not vary greatly from Seneca to Piscataway, and the use of the transferred water temperature record was viewed as an acceptable substitution.

THE CALIBRATION PROCESS

Model calibration is an iterative procedure of parameter evaluation and refinement where simulated water quality outputs are compared with observed data. The general steps of the calibration process for sediment and water quality constituents are outlined below and follow the procedures set forth in the HSPF application guide (Anderson Nichols, 1982).

1. A calibration interval was selected, based on the quality of the available water quality data base. In the Piscataway watershed, the 17-month NURP monitoring effort represented the most complete dataset for the comparison of simulated and observed values. Therefore, the calibration interval extended from August 1, 1980 to December 31, 1981.

2. The observed water quality data was reduced to a level where it could be directly compared to model outputs. In the Piscataway Creek application this involved transforming the monitored data collected from NURP into individual baseflow, storm event, and cumulative mass loadings for each water quality constituent.

3. An initial estimation of model parameter values was made. This step necessitated the review of all pertinent information and reports from Piscataway and adjacent streams that related to model applications and watershed characteristics. From this information, much of which is referenced in Appendix B and previous Piscataway Watershed Study reports, the initial model input stream was constructed.

4. The model was executed and observed and simulated values were compared. Iterative adjustments to specific rates or coefficients were made in successive model runs in order to minimize differences between observed and simulated values. Simulations were judged in reference to observed instantaneous baseflow concentrations, storm event mass loads, and cumulative 17-month loads.

5. The calibration process was continued until a good level of correspondence was reached for all of the water quality constituents. This level is derined by Anderson Nichols (1982) as agreement with 10 percent for hydrology, 15 percent for sediment, and 20 percent for nitrogen, phosphorus and dissolved oxygen on an annual or monthly basis.

CHAPTER 3. RESULTS OF MODEL CALIBRATION

HYDROLOGY

Because of the close relationship between watershed hydrologic processes and the generation and transport of sediment and water quality constituents, a great deal of effort was directed toward this aspect of the model application. As background, nine years of hydrological and meteorological records were used in the original hydrologic calibration and verification (MWCOG, 1982). Several illustrations of the results of this work are presented. As shown in Figure 3.1, annual runoff was accurately simulated over a four year calibration period and a five year verification period in which a wide variability in flow was observed on an annual basis. The flow duration analysis in Figure 3.2 demonstrates that the watershed model successfully simulated the observed frequency of flow events over the calibration period. And on an individual storm basis, the simulated hydrograph in Figure 3.3 for the storm of February 2-3, 1973 shows close agreement with the observed storm hydrograph. Based upon the thorough assessment carried out in this effort, it was thought that the watershed model was very capable of simulating the response of Piscataway Creek to a broad range of hydrometeorological conditions. Further detail is available in the above mentioned calibration and verification report.

Before commencing with the water quality and sediment calibration, it was necessary to establish that the model adequately simulated the stream hydrology for the period in which water quality data on Piscataway Creek was collected as part of COG's overall NURP study. The results of this effort for the seventeen month NURP period are shown in Figure 3.4 in units of inches of runoff. Overall the simulation was quite good, especially considering that runoff from storms and baseflow was only 25 percent of normal for this period. Total simulated runoff was 6.2 inches while total observed runoff was 5.5 inches. A trend toward oversimulation from February to June was principally due to simulated baseflow levels that were slightly higher than observed. Simulated and observed storm flows during this period, however, were quite similar. The largest storm occurred during June

FIGURE 3.1
Annual Discharge
Piscataway Basin

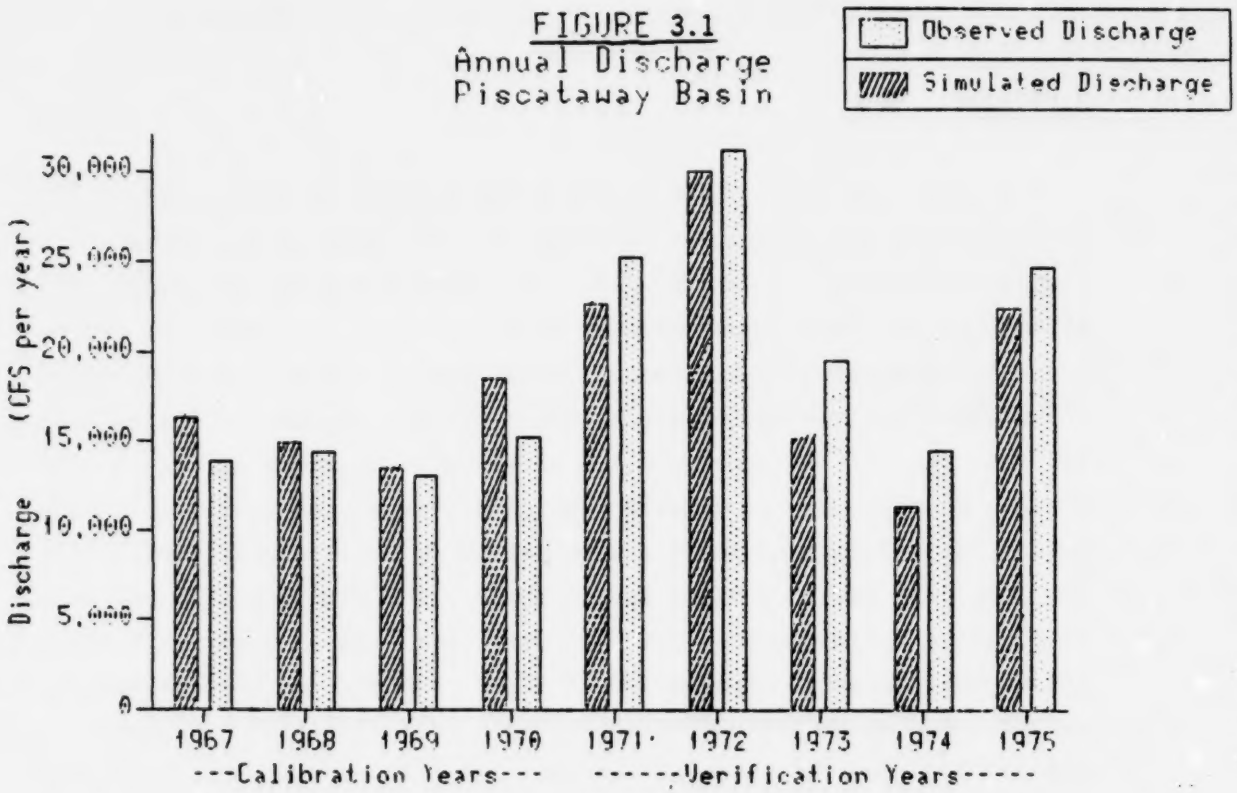


FIGURE 3.2
Observed and Simulated Flow Duration Curves
Piscataway Creek:Calibration Interval 1967 - 1970

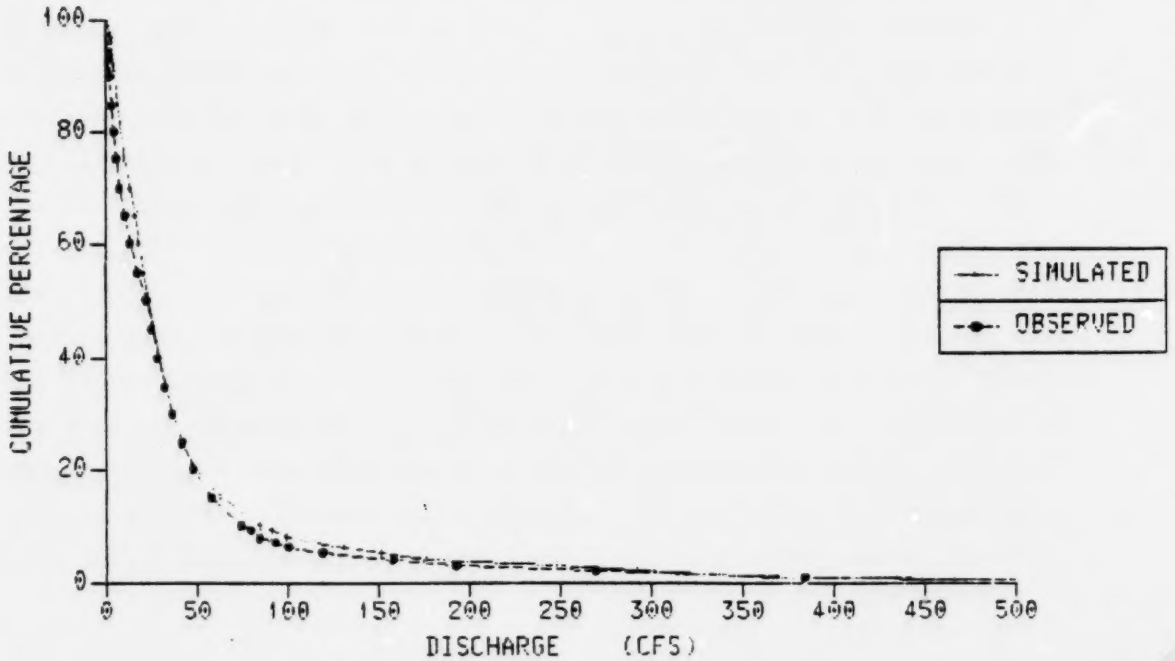


FIGURE 3.3
PISCATAWAY CREEK MAXIMUM YEARLY FLOW
STORM EVENT OF 2 - 3 FEBRUARY 1973

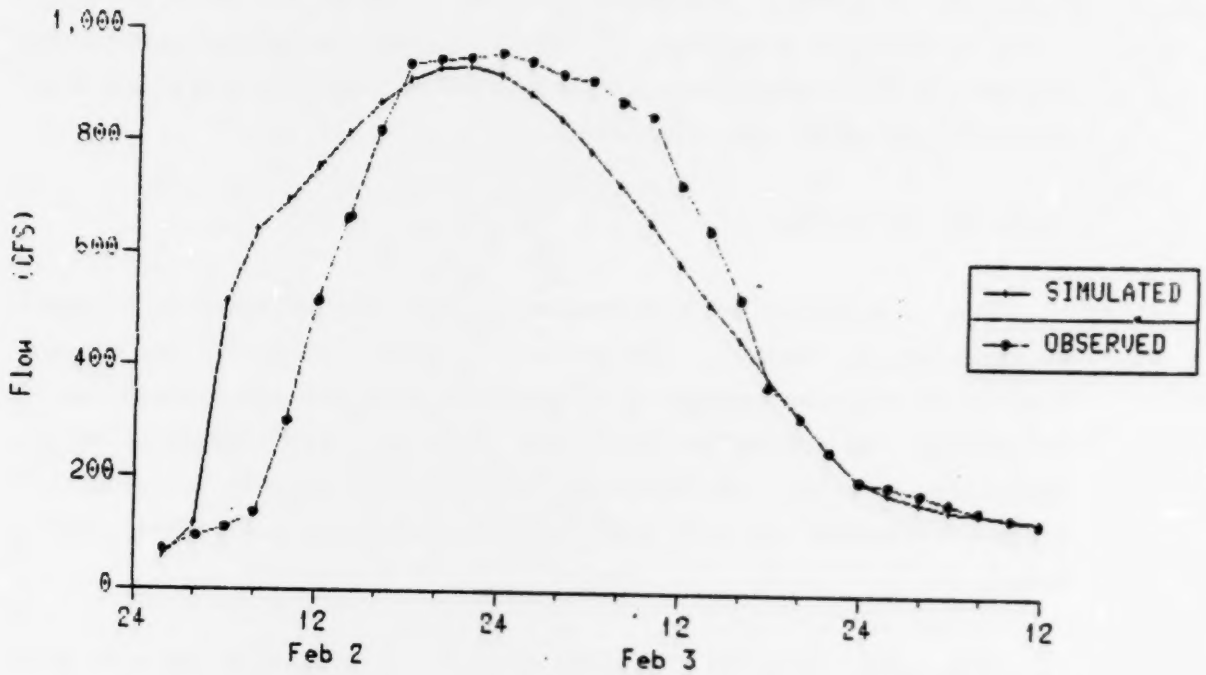
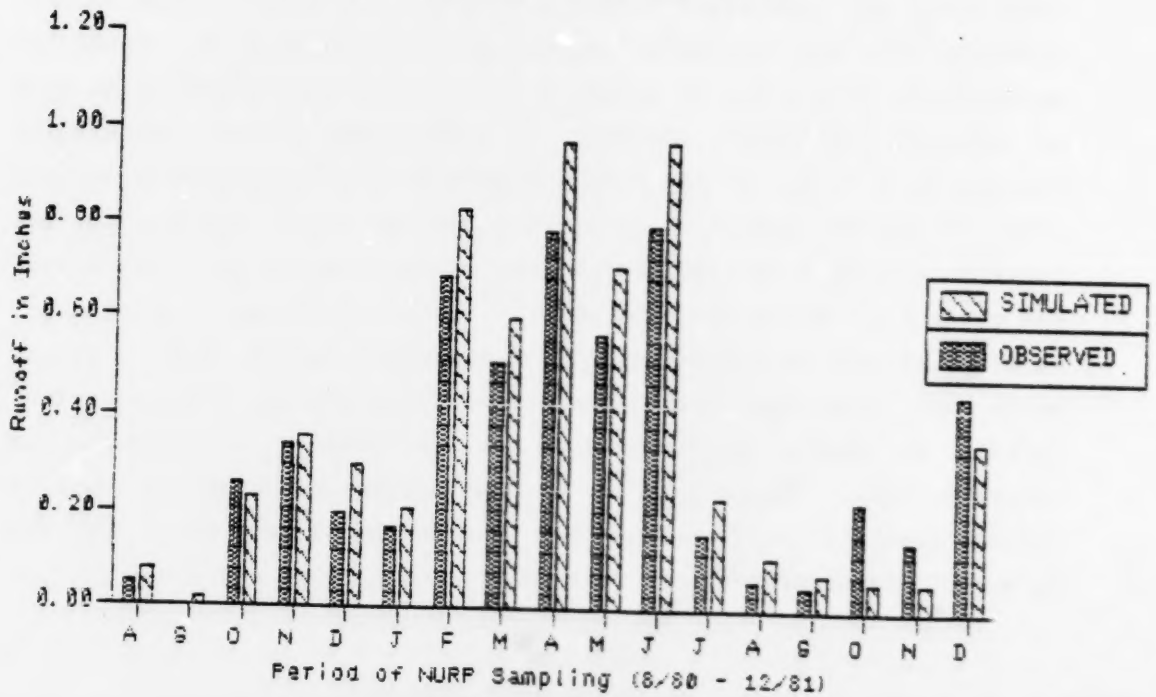


FIGURE 3.4
Comparison of Observed and Simulated Runoff in Inches
Piscataway Creek
1980-1981 NURP Sampling Period



with a peak flow rate of 669 cubic feet per second (cfs). On a volume basis, the simulated value for this event was 500 cubic feet per second per day (cfsd) which was quite close to the 475 cfsd that had been observed. In summary, the ability of the model to represent the principal hydrologic processes of the Piscataway watershed, even under extreme low flow conditions, was demonstrated, and the hydrologic component of the model was reverified.

DISSOLVED OXYGEN/BOD

The simulation of dissolved oxygen was accomplished in a rather straightforward manner. The principal factors affecting the concentration of dissolved oxygen in Piscataway Creek are temperature, as it determines the saturation level, and aeration. Waste loads of oxygen demanding material, nitrification, and decaying organic matter within bottom sediments do not have much impact upon the dissolved oxygen budget.

The only observed dissolved oxygen data available was from grab samples taken chiefly during low flow periods. There was no observed data associated with storms, but it is probably safe to assume that dissolved oxygen concentrations during storms were at or near saturation because of turbulence and reaeration. Figure 3.5 presents a comparison of simulated versus obsreved dissolved oxygen concentrations for the seventeen month NURP sampling period. By way of explanation, this graph is termed a "one-to-one" plot since it is used to compare individual observed vs. simulated values. Each point represents a pair of observed and simulated concentrations, and its proximity to the diagonal line of equal values (where observed concentrations are equal to simulated concentrations) serves as a measure of the quality of the calibration effort. Points above the line of equal values indicate an oversimulation of dissolved oxygen, whereas points below the line suggest that the dissolved oxygen has been undersimulated. As shown, the simulated values closely approximate the observed data, and most of the points throughout the entire range of values are clustered around the one-to-one line. Based upon the agreement demonstrated on this plot, it was felt that the principal

FIGURE 3.5

Comparison of Simulated and Observed Dissolved Oxygen Concentrations
Piscataway Creek
1980-1981 NURP Monitoring Interval

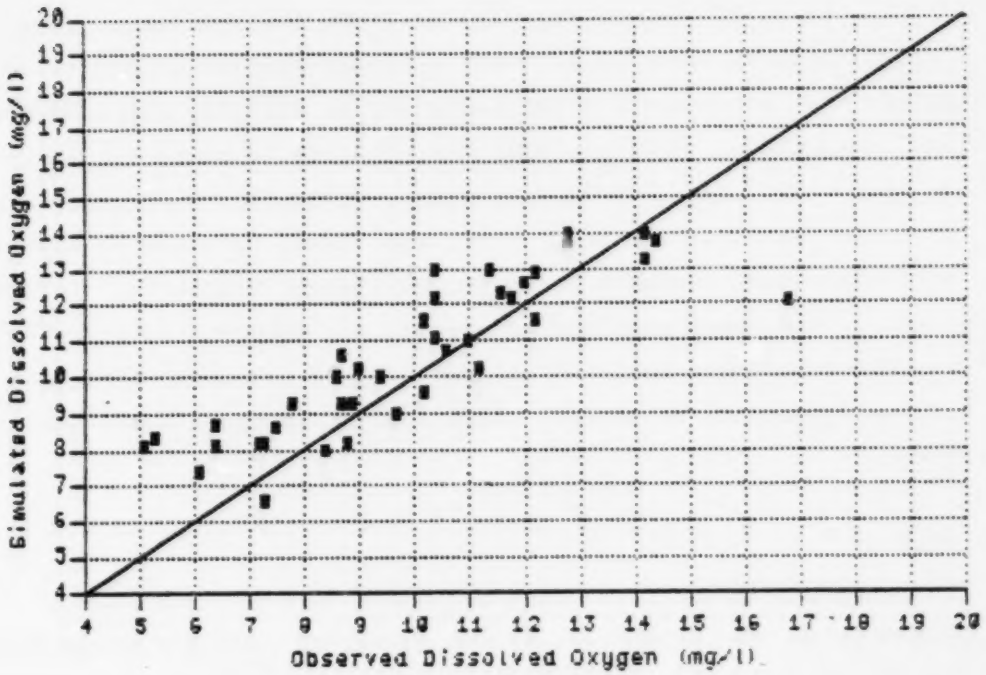
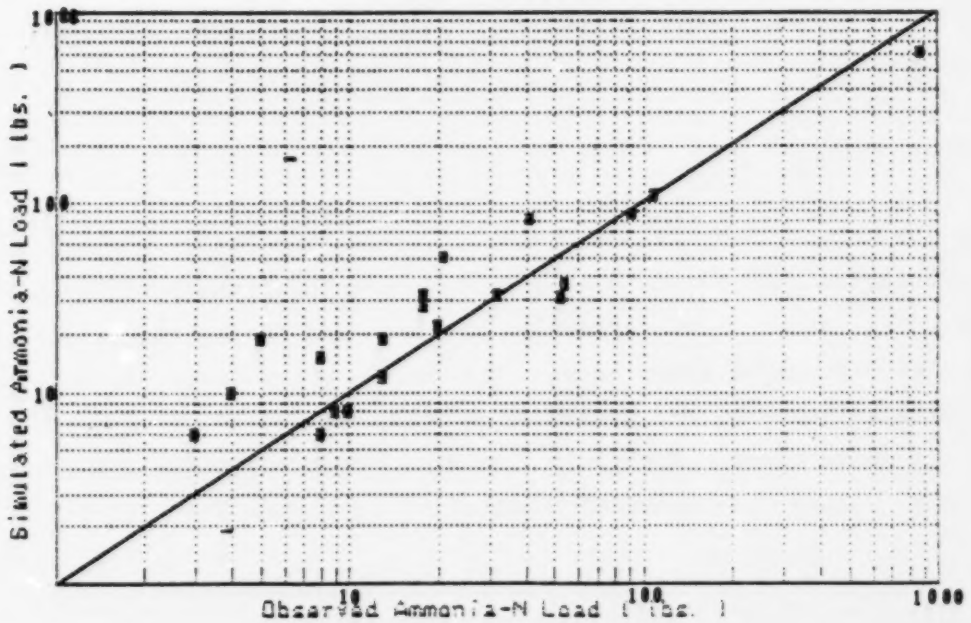


FIGURE 3.6

Comparison of Simulated and Observed Individual Storm Ammonia-N Loads
Piscataway Creek
1980-1981 NURP Monitoring Interval



processes affecting dissolved oxygen in Piscataway Creek were being modeled in an acceptable manner.

Very little BOD data was available for the simulation period, and, unfortunately, there were no storm runoff samples of BOD at all. Therefore, the storm simulations could not be directly compared with observed conditions, and it was not possible to carry out a calibration for BOD. The BOD loading rates, subsurface concentrations, and instream settling and decay rates were based upon the "Guidebook for Screening Urban Nonpoint Pollution Management Strategies" (NVPDC, 1980) and other local modeling studies in the Occoquan Basin (NVPDC, 1979). The confidence assigned to this part of the model application is not as great as it is with other fully calibrated water quality parameters.

NUTRIENTS

Comparisons of simulated versus observed nutrient values were possible on three levels: plots of individual storm loads; bar graphs of cumulative storm loads; and bar graphs of combined storm and baseflow loads over the seventeen month NURP sampling period. The determination of this last measure, the combined seventeen month loads, is discussed in detail in the previously mentioned assessment of water quality in Piscataway Creek (MWCOG, 1983). The results of the calibration effort are described below for individual nutrient constituents.

Ammonia

The comparison of individual simulated and observed storm loads is presented on Figure 3.6, a plot with a logarithmic scale on both axis. As shown, close agreement was obtained during the calibration for a wide range of storm loads. Cumulative storm loads for nutrients as well as sediment are presented in Figure 3.7, and the ammonia values are quite close. Similarly, the total combined storm and baseflow ammonia values are quite close as shown in Figure 3.8. It should be

FIGURE 3.7
Comparison of Observed and Simulated Cumulative Loads
Piscataway Creek
All 1980-1981 NURP Storm Events

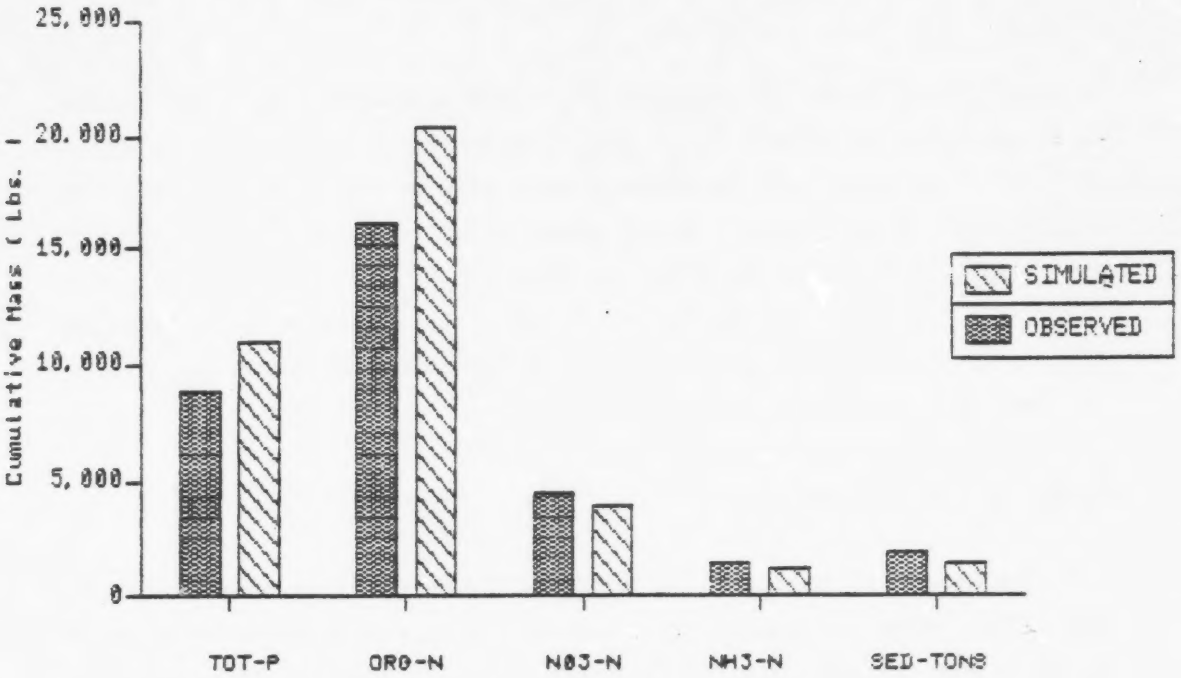
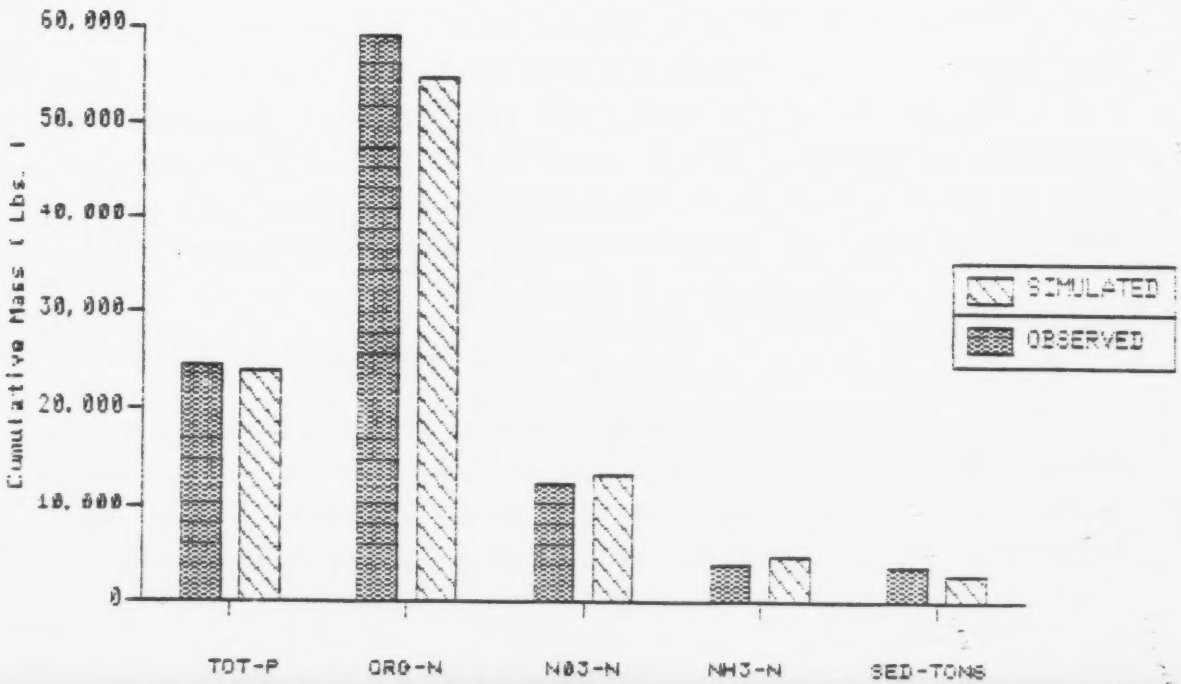


FIGURE 3.8
Comparison of Observed and Simulated Cumulative Loads
Baseflow and Stormflow Periods
Piscataway Creek (8/80 - 12/81)



noted that ammonia loads were generally very low in comparison to other forms of nitrogen.

Nitrate

The simulation of nitrate was quite successful as shown in the one-to-one plot of Figure 3.9. The cluster of points around the diagonal line of equal values demonstrated that nitrate was simulated in an adequate manner over a broad range of storm events. On a cumulative storm load basis, as shown in Figure 3.7, the simulated load was within 12 percent of the observed load. In regard to total nitrate loads over the sampling period, the simulation was within 7 percent of the observed load shown in Figure 3.8.

Total Organic Nitrogen (TON)

The most abundant of the nutrient forms in Piscataway Creek was TON. The data indicated that TON was closely associated with storm runoff, and it was decided to handle it as a conservative substance since its residence time within Piscataway Creek would be less than a day, and less than the time required for significant transformations to take place. The plot of simulated versus observed storm loads on Figure 3.10 shows good agreement for the full range of storms within the period. On the bar graph of cumulative storm loads on Figure 3.7, the simulated load is 26 percent greater than the observed load. Almost all of this oversimulation was in the one large runoff event which occurred during June, 1981. The simulated total for the entire seventeen month period, however, was within 7 percent of the observed value as shown in Figure 3.8. Taken together these three tests showed that TON was adequately simulated with the calibrated watershed model.

Total Phosphorus

Total phosphorus, like TON, was also closely related to storm runoff. Much of the total phosphorus in storm loads was in the particulate form, while most observed during baseflow periods was dissolved. It was therefore practical to treat total phosphorus as a

FIGURE 3.9
Comparison of Simulated and Observed Individual Storm Nitrate-N Loads
Piscataway Creek
1980-1981 NURP Monitoring Interval

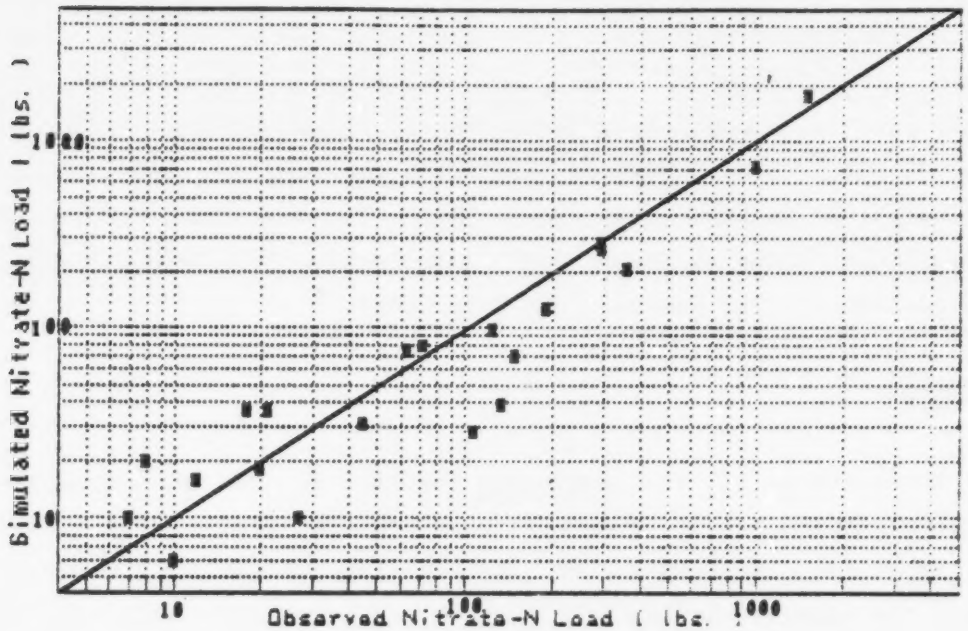
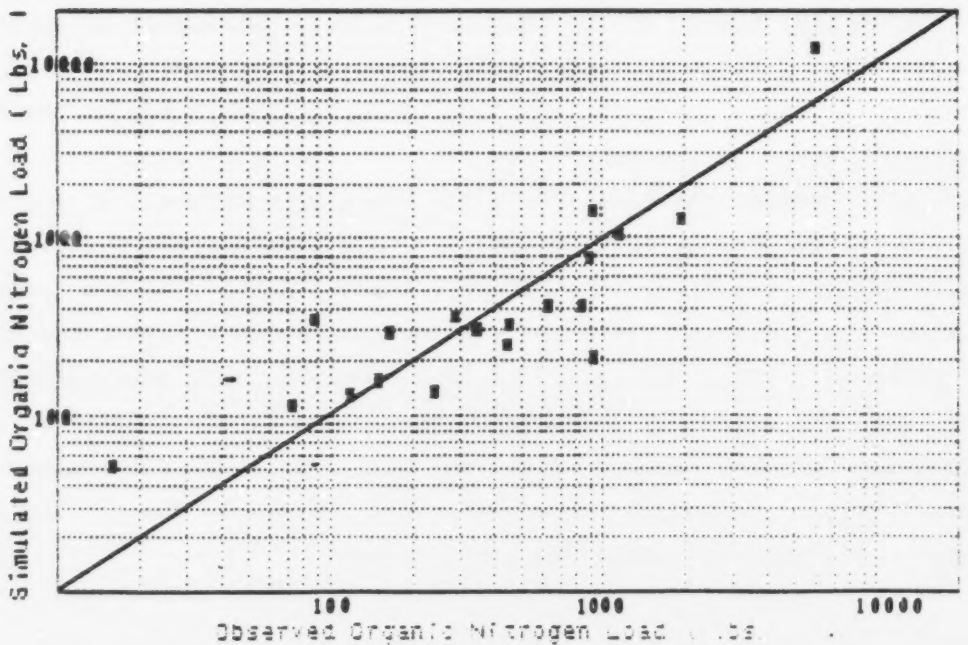


FIGURE 3.10
Comparison of Simulated and Observed Total Organic Nitrogen Loads
Piscataway Creek
Storm Events During 1980-1981 NURP Interval



conservative substance in the model. On an event-by-event basis, the simulation of total phosphorus was quite good. Most of the values plotted on Figure 3.11 are tightly clustered around the line of equal values. On Figure 3.7, the cumulative storm graph, simulated total phosphorus is shown to be approximately 25 percent greater than the observed storm total. Most of this difference was the result of over-simulation of the one large storm event. The comparison of simulated and observed values on Figure 3.8 for the entire seventeen month period shows a close agreement within 2 percent.

SEDIMENT

Calibration of the sediment portion of the watershed model required achieving a balance between sediment washoff from pervious and impervious surfaces, and the settling and scouring of sediment within the channel reaches. This proved to be a rather difficult task because of the very low amount of precipitation which fell during the seventeen month NURP sampling period. One result of this was that little surface runoff was generated because the ground was seldom saturated. Consequently, erosion and the washoff of sediments was minimized during this period. The results of the calibration effort, however, were far from discouraging. A comparison of simulated and observed storm yields is presented on Figure 3.12. Most of the plotted points are clustered around the full length of the one-to-one line, although there is a tendency toward undersimulation of some events. One of the most important features on this plot is the close agreement between observed and simulated yield achieved for the one large storm event of the year. The plot of cumulative storm yields on Figure 3.7 shows the simulated value to be approximately 25 percent less than the sum of observed yields. Similarly, the comparison of total sediment yield over the entire seventeen month period on Figure 3.8 shows the simulated yield to be approximately 25 percent less than the observed yield. Taking all of these measures into consideration, along with the extremely dry period represented by the NURP data, the calibration results showed that the watershed model was adequately simulating the principal processes that determine the erosion and transport of sediment within Piscataway Creek.

FIGURE 3.11
Comparison of Simulated and Observed Individual Storm Total Phosphorus Loads
Piscataway Creek
1980-1981 NURP Monitoring Interval

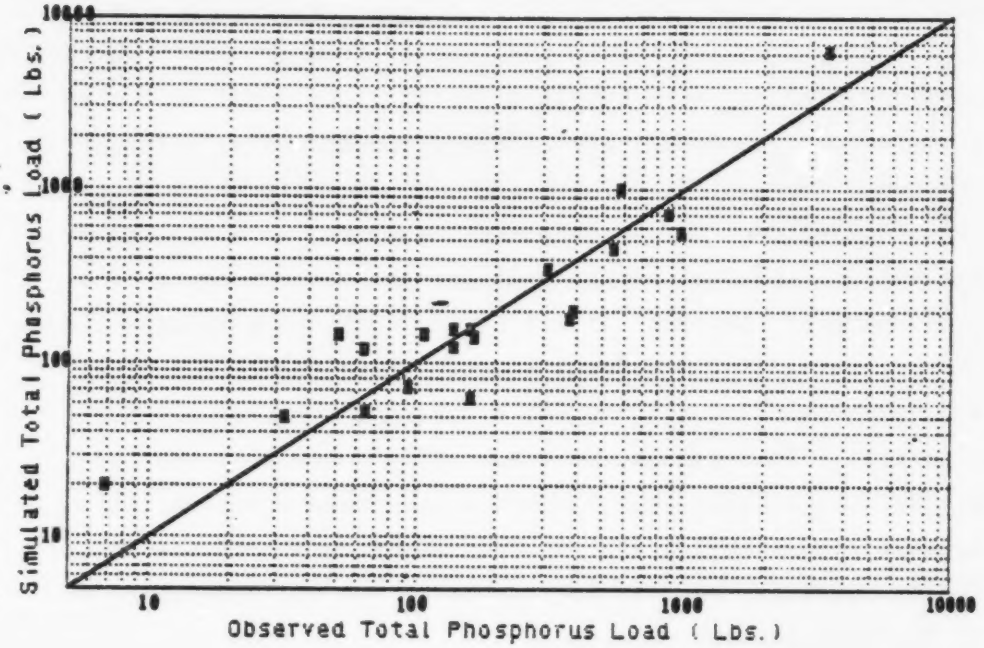
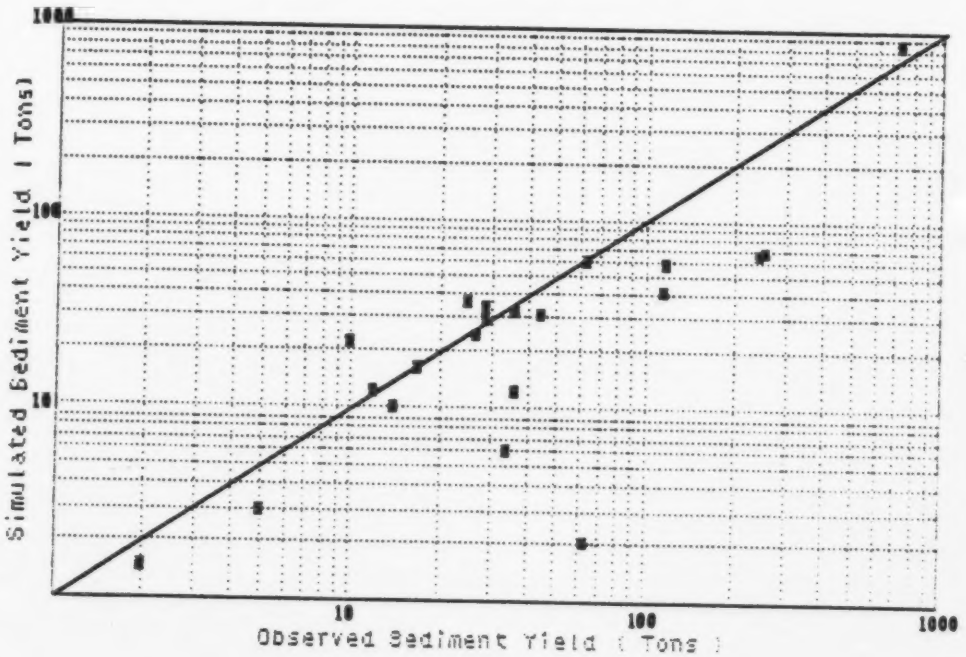


FIGURE 3.12
Comparison of Simulated and Observed Individual Storm Sediment Yields
Piscataway Creek
1980-1981 NURP Monitoring Interval



SUMMARY OF CALIBRATION RESULTS

The ability of the Piscataway Watershed Model to simulate flow was demonstrated over a nine year calibration and verification period in which flows varied greatly, and an additional seventeen month period that corresponded to the NURP sampling period. The model also simulated the physical, chemical and biological processes affecting dissolved oxygen, nutrient loads, and sediment generation and transport in the watershed. Three separate measures were applied to compare calibration results of the sediment and water quality calibration. The general pattern of agreement between simulated and observed values for all of the water quality constituents was established graphically and in the context of percent differences within reasonable limits. This was accomplished using a sediment and water quality calibration dataset that spanned a seventeen month period of less than average precipitation and runoff. Verification of the sediment and water quality aspects of the model was not undertaken as there was no separate dataset available.

In summary, the Watershed Model adequately represents the major processes that account for the generation and transport of sediment and nonpoint source constituents in Piscataway Creek.

CHAPTER 4. MODEL PROJECTIONS AND IMPACTS

One of the principal reasons for developing a watershed model was to project changes in water quantity and quality that would be expected to occur as development proceeded in the Piscataway watershed. In order to accomplish this in a meaningful manner, one year of meteorological records (1971) representing a rather typical or average rainfall year was singled out. The hydrology and sediment components of the model, coupled to a network representing the current land use configuration within the watershed, were executed with the average meteorological year as input. It was assumed that there were no stormwater or nonpoint source controls of significance within the watershed. The results of this simulation were subsequently compared to a similar model application with a network representing the "planned" or future land use conditions, also without stormwater or nonpoint source controls, which was provided by M-NCPPC (see Table 2.3 or Appendix A for details). Comparison was also made to a hypothetical predevelopment condition in which the watershed was assumed to be 100 percent forest. Additional comparisons that include the effectiveness of implementing a control program are presented in Chapter 5.

Major trends contemplated in the future land use are the conversion of most of the forest and nearly all of the agricultural land within the watershed to residential development of varying density. In terms of impervious cover, this translates to an overall increase from approximately 11 percent to 30 percent for the watershed. Changes in hydrology and water quality projected by the Piscataway model for this level of development in the absence of control practices are summarized in Table 4.1 and discussed below. Specific impacts that would be expected to occur as a result of these projected changes are also presented.

HYDROLOGY

The increase in imperviousness associated with the future land use situation produced several unsurprising changes in water quantity. As shown in Table 4.1, total annual flow and average daily flow

Table 4.1

MODEL PROJECTIONS: EXISTING AND FUTURE DEVELOPMENT
UNDER AVERAGE ANNUAL METEOROLOGICAL CONDITIONS

	EXISTING	FUTURE	PERCENT CHANGE
HYDROLOGY			
Total Annual Flow	13,240 cfsd	19,410 cfsd	+ 47%
Average Daily Flow	36 cfs	53 cfs	+ 47%
Peak Daily Flow	882 cfsd	1,046 cfsd	+ 19%
Impervious Runoff	2,371 cfsd	9,821 cfsd	+314%
Subsurface Flow	7.56 inches	6.32 inches	- 16%
WATER QUALITY			
Ammonia	10,630 lbs	13,950 lbs	+ 31%
Nitrate & Nitrite	27,770 lbs	30,660 lbs	+ 10%
Total Organic Nitrogen	137,400 lbs	204,400 lbs	+ 49%
Total Phosphorus	68,130 lbs	106,000 lbs	+ 56%
SEDIMENT			
Average Annual Yield	15,650 tons	29,510 tons	+ 89%
Average Net Scour	4,330 tons	12,690 tons	+193%

increased by 47 percent. A 19 percent increase in storm flow from 882 cfsd to 1046 cfsd was also projected for the highest day of flow during the average year conditions that were simulated. The corresponding increase in the instantaneous peak flow rate would presumably be greater. In terms of low flow, the future year projection called for a decrease in baseflow of 16 percent. The ramifications of this upon the aquatic life within Piscataway Creek could be substantial as low flows and periods of no flow would tend to increase in frequency as well as duration as a result of reduced infiltration and groundwater replenishment. Runoff from impervious areas, which often represents the bulk of urban stormwater, was projected to increase by nearly 200 percent, in proportion with the increase in impervious acreage.

DISSOLVED OXYGEN/BOD

No substantial changes to the dissolved oxygen balance within Piscataway Creek were projected under the future land use condition. An increase in the BOD load generated within the watershed of 78 percent was projected. However, this number should be used as indicative of a general trend and not accepted at its face value since the lack of observed BOD data precluded an adequate calibration of the BOD component of the model.

NUTRIENTS

As shown in Table 4.1, the changes projected for nutrients were quite variable from one constituent to another, reflecting the variability in loadings from different land uses and hydrologic pathways. For ammonia, an increase of 31 percent was projected for the future land use situation. Most of this can probably be attributed to the increase in impervious surfaces. However, the ammonia load as projected would still be quite small and at a level where ammonia would probably not present a problem to either Piscataway Creek, the Piscataway Embayment, or the Potomac estuary.

The nitrate load under the future land use situation was projected to increase by about 10 percent. The subsurface component of the

nitrate load is slightly diminished by the substitution of residential usage for agricultural usage and the greater coverage of impervious surfaces. However, the relatively small 10 percent increase indicates that this would be offset by the higher yields associated with surface runoff from residential areas and in particular from the additional impervious area.

A substantial increase in total organic nitrogen (TON) of 49 percent was projected with the future land use. This increase is particularly meaningful as TON, at 82 percent of total nitrogen under the future condition, is the dominant form of nitrogen generated within the watershed. Much of the projected increase can be attributed to the washoff of TON from impervious surfaces. For the most part, the TON originates from local vegetative matter and atmospheric sources. That which accumulates on impervious areas is subject to washoff during storms.

The projected future load for total phosphorus also showed a substantial increase of 56 percent. Like TON, much of this increase can be directly attributed to the change in imperviousness. The projected increase represents a potential problem because it calls for the delivery of more nonpoint source phosphorus to the Piscataway embayment and to the upper Potomac estuary, two areas where eutrophication has been a problem over the past two decades.

For the upper Potomac estuary, the water quality management strategy employed by local jurisdictions over the past ten years has been to reduce the delivery of phosphorus to this receiving water by removing phosphorus at sewage treatment plants, a costly undertaking. For the Piscataway embayment, the State of Maryland has recognized the limited ability of this shallow body of water to assimulate phosphorus and other pollutants. Thus the state established a limit on the amount of pollutants including phosphorus that could be discharged directly into the embayment from the Piscataway Sewage Treatment Plant (STP). As a result, the outfall of the STP has recently been moved out of the embayment to a point where it discharges directly into the mainstem of the Potomac River. Increased nonpoint phosphorus loads

could pose a threat to the improved water quality conditions that have been realized as a result of the phosphorus removal program and the placement of the Piscataway STP outfall in the main channel of the Potomac.

SEDIMENT

The most profound change associated with the future land use configuration within the watershed was in the area of sediment generation and transport. As indicated on Table 4.1, the total outflow or flux of sediments from the watershed is projected to increase markedly by 89 percent from over 15,000 to over 29,000 tons per year. The principal reason for this substantial change is the projected 190 percent increase in channel scour. This nearly threefold increase in channel scour over existing conditions represents a great deal of net stream bank erosion and bed scour. The impact of changes in erosion, scour and sedimentation at this scale would probably be very detrimental to the aquatic life and wildlife habitat within Piscataway Creek. Several specific consequences that might result from a change in the sediment balance as projected are as follows:

- As imperviousness increases, the amount of uncontrolled stormwater in the watershed would increase. In addition, the magnitude of the two-year peak flow, the flow that largely controls streambank erosion, would also increase. One result of this would be an increased occurrence in streambank erosion as the stream established a new equilibrium. Channel widening is the usual expression of this phenomena. Numerous adverse impacts upon the habitat and its ability to support a diverse community of species would be attendant with channel widening. These include loss of riparian vegetation and less shade, alteration of the natural stream temperature regime, fewer pools, more frequent debris dams that pose barriers to migration, and alteration of the composition of stream bed materials.

- Sedimentation would become more and more of a problem if the gross amount of sediment transported through the stream increased as projected. The extent of viable instream habitat would be reduced as a result of sedimentation. A major consequence would be a reduction in spawning areas for both freshwater as well as anadromous fish species.

- The frequency and occurrence of total suspended sediment concentrations at levels dangerous to fish and other types of aquatic life would increase. As shown in Figure 4.1, the percent of time that sediment concentrations equalled or exceeded 100 mg/l is projected to increase significantly, especially in the lower reaches of Piscataway Creek. 100/mg/l is used here as a suggested criteria for the protection of aquatic life, and is based upon the recommendations of the American Fisheries Society (Thurston, et. al. 1974). Changes in average annual peak sediment concentration are also projected to increase as shown in Figure 4.2 for the seven channel reaches modeled. The shock effect of these high sediment concentrations would be harmful if not lethal to aquatic life.

- A large increase in the amount of sediment transported to the Piscataway embayment and the Upper Potomac estuary would occur. The adverse impacts of this upon these tidal waters would include sedimentation, reduced levels of water clarity, and possible losses in the submerged aquatic vegetation community due to decreased light penetration.

SUMMARY OF MODEL PROJECTIONS AND IMPACTS

The "planned" land use situation would significantly increase the amount of impervious cover within the watershed. In the absence of stormwater or nonpoint source controls, the following effects upon hydrology, sediment, water quality and wildlife habitat within the

FIGURE 4.1
Piscataway Creek
Comparison of Sediment Frequency at or Above 100 mg/l

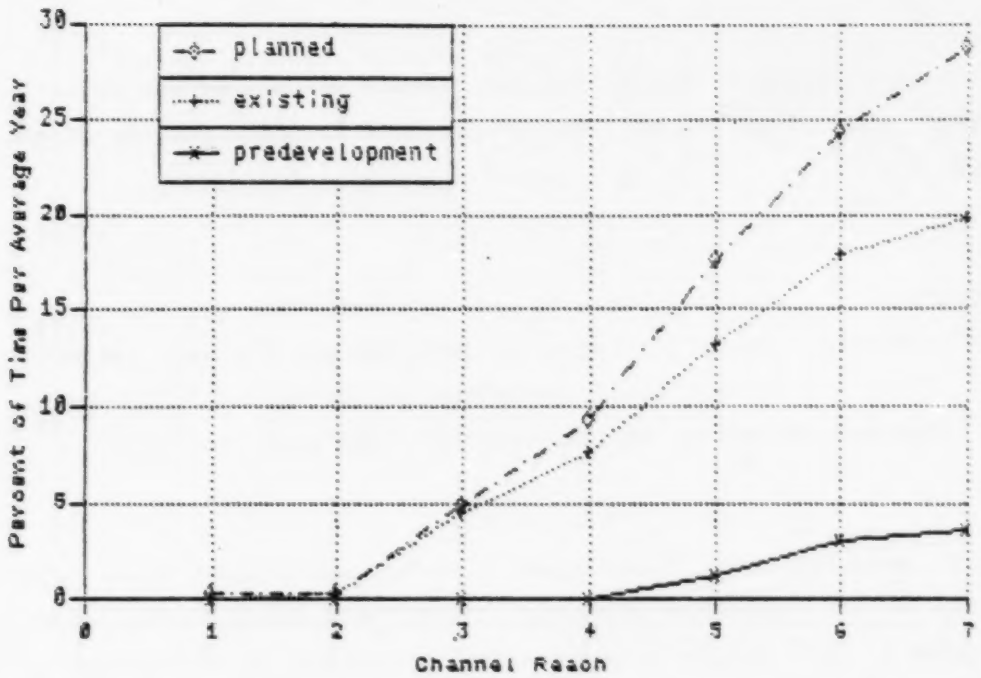
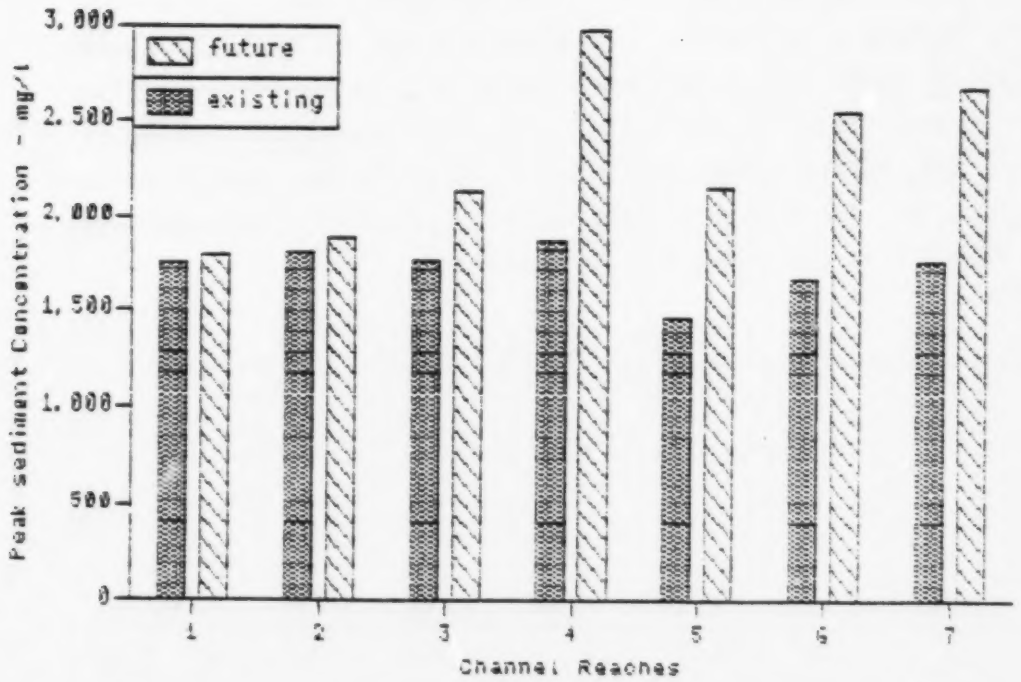


FIGURE 4.2
Piscataway Creek
Comparison of Average Annual Peak Sediment Concentrations



watershed were projected with the Piscataway Watershed Model under average meteorological and flow conditions:

- Hydrologic changes would include larger volumes of stormwater, higher peak flow rates, and longer more frequent periods of no flow.

- Increases in the neighborhood of 50 percent for average annual loads of total organic nitrogen and total phosphorus were projected. These increases would contribute to eutrophication problems in Piscataway embayment and the Upper Potomac estuary.

- Total sediment load, streambank erosion and channel scour were projected to increase markedly. This would result in increased turbidity and reduced water clarity, increased concentrations of sediment at levels exceeding those recommended for the health of aquatic life, and damaged wildlife habitat due to bank erosion and sedimentation.

Without the implementation of appropriate runoff controls coincident with planned future development, the Piscataway model projections indicates changes will occur in water quality and the physical stream regime which could be very detrimental to the future support of diverse aquatic life in the basin. The next chapter of this report discusses the effectiveness and suitability of various practices for controlling the increases in stormwater, pollutant loadings, and related problems as projected for the watershed.

CHAPTER 5.
MANAGEMENT OF STORMWATER AND NONPOINT POLLUTANTS IN THE PISCATAWAY WATERSHED

The "planned" land use information provided by M-NCPPC indicates that extensive development within the Piscataway watershed is contemplated for the future. In the absence of suitable runoff controls, significant increases in the generation of sediment and nonpoint source pollutants were projected. Stormwater management planning for the watershed that takes this future growth into consideration is underway as a Comprehensive Management Plan for Piscataway Creek is being drafted. Alternatives currently under consideration in that effort by the Stormwater Management Technical Committee include the acquisition of flood prone structures, installation of levee systems, flood proofing, and the construction of various regional off-site detention facilities (Prince George's County, 1982).

The main thrust of the management alternatives under consideration by the Stormwater Committee is flood control and the reduction of peak flow increases expected from development and a higher degree of impervious land cover. All five of the alternatives involve structural measures that would include the construction of one or more detention (dry) basins, while one combines an extensive levee system with a detention basin. A major feature of the four non-levee alternatives would be the construction of either one or two large detention facilities along the main channel of Piscataway Creek. These facilities would have storage volumes on the order of 800 to 1450 acre-feet, and would be drained by three or four 96-inch diameter pipes. Several of the alternatives also include smaller detention basins on tributaries to Piscataway Creek.

In general, the structural alternatives under consideration by the Stormwater Management Technical Committee would probably provide a high level of flood control protection for rather rare storm events. However, they would appear to offer only very limited erosion and water quality benefits. This is because these structural alternatives do not incorporate sufficient time for settling, infiltration and

biological uptake, the principal pollutant removal mechanism, into their design. Also, such structural alternatives are not designed to control runoff from the smaller runoff events that occur rather frequently. Extensive field sampling conducted for COG in the Washington region has shown that the small and frequently occurring local storms are responsible for the generation of much sediment and nonpoint pollutants.

The overall thrust of research funded under the EPA Nationwide Urban Runoff Program was upon urban runoff and nonpoint source pollution loadings and their related effects upon water quality. The flood control objectives of the Stormwater Committee's structural alternatives for Piscataway went beyond these objectives and were therefore not evaluated extensively. However, the potential for multipurpose BMPs as control measures capable of providing erosion, water quality and stream habitat protection was evaluated. These alternatives could also be designed to provide some flood control benefits for storms that occur with 2-10 year frequencies.

Wet ponds were selected for this example since they were observed to be a very effective BMP during the NURP project, and it was thought that their application within the Piscataway watershed would be illustrative of the maximum amount of control that could be achieved. Under this kind of a control program, the wet ponds were also capable of maintaining peak runoff for the two-year storm at predevelopment levels.

WET PONDS AS A BMP STRATEGY

As a means of evaluating a management strategy for the Piscataway watershed, information on the effectiveness of wet ponds from COG's NURP study (MWCOG, 1983) was utilized. Nonpoint source loads from areas that are expected to be developed in the future were simulated with the watershed model as discussed in the previous chapter. To project the effectiveness of nonpoint source controls, sediment and pollutant removal efficiencies were applied directly to surface generated storm loads in areas that are expected to change from forest,

agriculture or open land to residential or commercial development. The removal efficiencies applied were as follows:

Constituent	% Removal
Nitrate and Nitrite	50%
Ammonia	50%
Total Organic Nitrogen	25%
Total Phosphorus	50%
Sediment	50%

In general, these wet pond efficiencies represent conservative estimates of removal efficiencies that were observed at field sites in suburban Maryland and Northern Virginia under COG's NURP study. In the analysis it was assumed that full application of wet ponds to 100 percent of all new development would be made. However, the retrofitting of controls to existing developed areas was not considered to be practical, and it was therefore not evaluated.

The intent of this approach was not to advocate wet ponds over other measures, but to demonstrate the maximum amount of control and reduction in loads that could be realized with a basinwide application of BMPs with new development. The results of this exercise as applied to projected loads based on the future or "planned" land use are discussed below. A summary of the projected loads and control effectiveness is presented in Table 5.1. For the sake of comparison, the previously mentioned predevelopment or 100 percent forested condition in the watershed was also simulated with the model. Such projections are useful as an approximation of background hydrologic and water quality conditions that might be expected in an undisturbed situation.

Nutrients

As shown on Table 5.1, a full application of BMP wet pond controls coincident with anticipated future growth could significantly

Table 5.1

SUMMARY OF PROJECTED PISCATAWAY LOADS

	PREDEVELOPMENT (100% FORESTED)	EXISTING CONDITION	PLANNED LAND USE	PLANNED (WITH CONTROLS)
Nitrate (lbs/yr)	23,200	27,770	30,660	22,770
Ammonia (lbs/yr)	7,980	10,630	13,950	6,960
Total Organic Nitrogen (lbs/yr)	96,600	137,400	204,400	169,500
Total Phosphorus (lbs/yr)	44,100	68,130	106,000	67,300
Total Sediment (tons/yr)	9,000	15,650	29,510	19,350
Net Scour (ton/yr)	3,220	4,330	12,690	8,510

reduce the generation and impacts of nutrient loading from storm runoff. For both nitrate and ammonia, average annual loads could be expected to be reduced to levels below existing conditions. Relatively small increases in both of these nutrients were projected under the planned land use condition without controls. The agricultural component as well as most of the forest component of the loading in the existing situation would be replaced by a vastly increased residential and commercial loading component in the planned uncontrolled land use situation. The slight increase in nitrate and ammonia loadings shown in the planned uncontrolled situation incorporates a net loss from the "rural component" offset by a slightly larger net gain from the "development component". The removal of 50 percent of this load with the application of wet ponds over the extensive area changed to residential and commercial development provides a very large nutrient reduction as shown in the planned (with controls) values in Table 5.1. This analysis suggests that predevelopment pound loadings for these two nutrients could even approach predevelopment levels with the widespread application of BMPs.

For total organic nitrogen, the implementation of wet ponds as controls could also be expected to stem the increase in loadings projected from the planned land use, but not to the extent shown for nitrate and ammonia. The values in Table 2 indicate that approximately half of the projected increase in load could be controlled.

The effectiveness of the ponds in controlling total phosphorus was substantial. As shown in Table 5.1, this control program would be able to hold the phosphorus load at about the same average annual level as projected under the existing condition. Control of phosphorus to this extent would be very beneficial to water quality in the Piscataway embayment and the Upper Potomac estuary as it would complement phosphorus removal at sewage treatment plants, which is currently the principal element in the region's strategy for the control of eutrophication in the Upper Potomac.

Stormwater and Sediment

In addition to providing for the removal of nutrients in urban stormwater, wet ponds can also provide significant levels of stormwater, sediment, and erosion control. Some of the sediment settles within the pond as runoff is detained. Based upon the performance of wet ponds monitored during NURP, a long term average reduction due to settling of 50 percent was applied. The attenuation of stormwater in the wet ponds also causes instream peak flow rates to be reduced. This effect lessens peak stream velocities, streambank erosion and bed scour. In an analysis of this type conducted at COG of the Little Seneca watershed in Montgomery County (Schueler and Sullivan, 1983) in which wet ponds were explicitly modeled, it was found that the application of these ponds caused significant reductions in the bank and channel scour projected with future land use alternatives. As a rule, reductions in scour increase as detention within the ponds is extended. For this Piscataway analysis it was assumed that a 50 percent reduction in the projected increase in scour could be achieved.

As shown in Table 5.1, total sediment could be reduced substantially from the uncontrolled planned land use condition with the application of wet ponds. The 10,000 ton reduction would make a substantial difference in offsetting the large increase in the sediment load and attendant adverse environmental problems projected under the uncontrolled situation. However, even with an extensive application of controls the sediment load is still expected to increase by 25 percent under full development as planned. Instream scour could also be expected to be reduced substantially. However, a doubling from existing conditions even under an extensive application of controls was still projected. Since sedimentation and stream bank erosion are currently a problem in Piscataway Creek, the increases in both scour and sediment load, even with controls, is disturbing as it would certainly have serious negative effects upon water quality and the aquatic and riparian habitats.

Cost of Wet Ponds

The cost of constructing, operating and maintaining BMPs is a major consideration in the selection of a management strategy. As a means of providing some information on costs, estimates were made of what it would take to implement a program such as the widespread use of wet ponds that has been described. Information on the capital, operating, and maintenance costs of wet ponds was derived from "An Evaluation of the Costs of Stormwater Management Pond Construction and Maintenance", another COG report recently completed as part of the NURP study (MWCOG, June, 1983).

Several assumptions concerning land use and pond requirements were necessary. These are summarized in Table 5.2. New development in the "planned" land use scenario was classified as being either high or low density, with the number of acres in need of management given for each. For the sake of uniformity it was assumed that off-site wet ponds would be used exclusively, with each 150 acres of new development in both high and low density categories requiring a pond. Storage requirements as well as costs were obtained from guidance provided in the above mentioned report on the cost of stormwater ponds. The cost estimates were prepared as shown in Table 5.2 assuming a twenty year project life, an eight percent discount rate, no land aquisition costs, and a common price base (1980 dollars).

Since the planned land use scenario represents a very substantial increase in the amount of developed land beyond what is currently in existence, a large number of wet ponds would be required. For a basinwide implementation of wet ponds with new development it was estimated that 114 ponds would be needed to accomodate the low density residential development, and another 12 ponds to handle stormwater from the more densely developed residential, commercial and industrial land uses. The estimate of total construction cost for all of the ponds was nearly $9.5 million. The annual operation and maintenance costs for all 126 of the ponds was estimated to be about $380,000. These calculations are also shown on Table 5.2.

TABLE 5.2

STORAGE AND COST ESTIMATES FOR OFF-SITE WET PONDS

Low Density Development:

- Rural and estale residential (categories 11, 112)
- Off-site pond: 150 acre drainage area
- Storage

permanent pool[1]	: 275,000 ft^3
required storage[2]	: 150,000 ft^3
Total	: 425,000 ft^3

- Costs

total construction cost	: $72,000
annual O&M	: $ 2,900

High Density Development:

- Denser residential, commercial and industrial (categories 113, 114, 115, 12, 13)
- Off-site pond: 150 acre drainage area
- Storage per pond

permanent pool[1]	: 275,000 ft^3
required storage[2]	: 600,000 ft^3
Total	: 875,000 ft^3

- Costs per pond

total construction cost	: $104,000
annual O&M	: $ 4,150

Basinwide Costs

- Total Construction Costs

low density development	
(114 ponds @ $72,000)	: $8,208,000
high density development	
(12 ponds @ $104,000)	: $1,248,000
Total Construction Costs	: $9,456,000

- Total Annual O&M

low density development	
(114 ponds @ $2,900)	: $330,600
high density development	
(12 ponds @ $4,150)	: $ 49,800
Total O&M Costs	: $380,400

[1]Provides for one-half inch of runoff over the drainage area for storage in the permanent pool.

[2]Required storage to maintain runoff of 2-year storm at pre-development levels.

The cost study also provides some guidance on the relative cost (construction plus O/M) per dwelling unit. Annualized total project costs per dwelling unit vary by density and would be approximately as follows: $78 per year for low density residential; $22 per year for medium density residential; and $9 per year for townhouse/garden apartment developments. In addition, the annualized cost for commercial development would be approximately $112 per acre.

The total construction costs represent an estimate of what it would cost to put wet ponds in place throughout the basin as it reached a high degree of development. Of course, in reality such development would be spread out over many decades, and the total cost would be spread out as well. Similarly, the operation and maintenance costs would start at a lower annual value and increase year after year as more ponds were put in place until full development had been reached. While these cost estimates must be viewed as preliminary, they are useful in the planning mode. A direct comparison with the cost of single purpose flood control management practices would be very valuable and instructive.

Additional Considerations

Several added benefits of wet ponds are rather intangible but nevertheless significant. In a recently completed citizen attitude survey in nearby Columbia, Md. which was conducted by the Urban Wildlife Institute (1983), the following results were obtained: 94 percent of residents felt it was desirable to design and manage stormwater basins for fish and wildlife; residents preferred wet ponds over dry ponds by a 4 to 1 margin; 75 percent of residents felt that wet ponds add to the real estate value of their homes; 73 percent expressed a willingness to pay more for homes situated near a wet ponds; and residents perceived wet ponds as having wildlife attraction, aesthetic and recreational benefits.

OTHER BEST MANAGEMENT PRACTICES

The above discussion was not intended to rule out the use or consideration of other control practices. Several other types of BMP's have equivalent pollutant removal efficiencies that would be suitable for implementation in the Piscataway watershed for the control of sediment, streambank erosion and nonpoint pollutants. The main point is that the implementation of some type of control strategy in conjunction with future development in the watershed could minimize the adverse consequences that development is projected to have upon water quality and the instream habitat. Summary information on the effectiveness or suitability of other types of best management practices studied under COG's overall NURP project are summarized below. A complete analysis of these practices can be found in the previously mentioned NURP final report (MWCOG, 1983).

"Dry" Detention Ponds

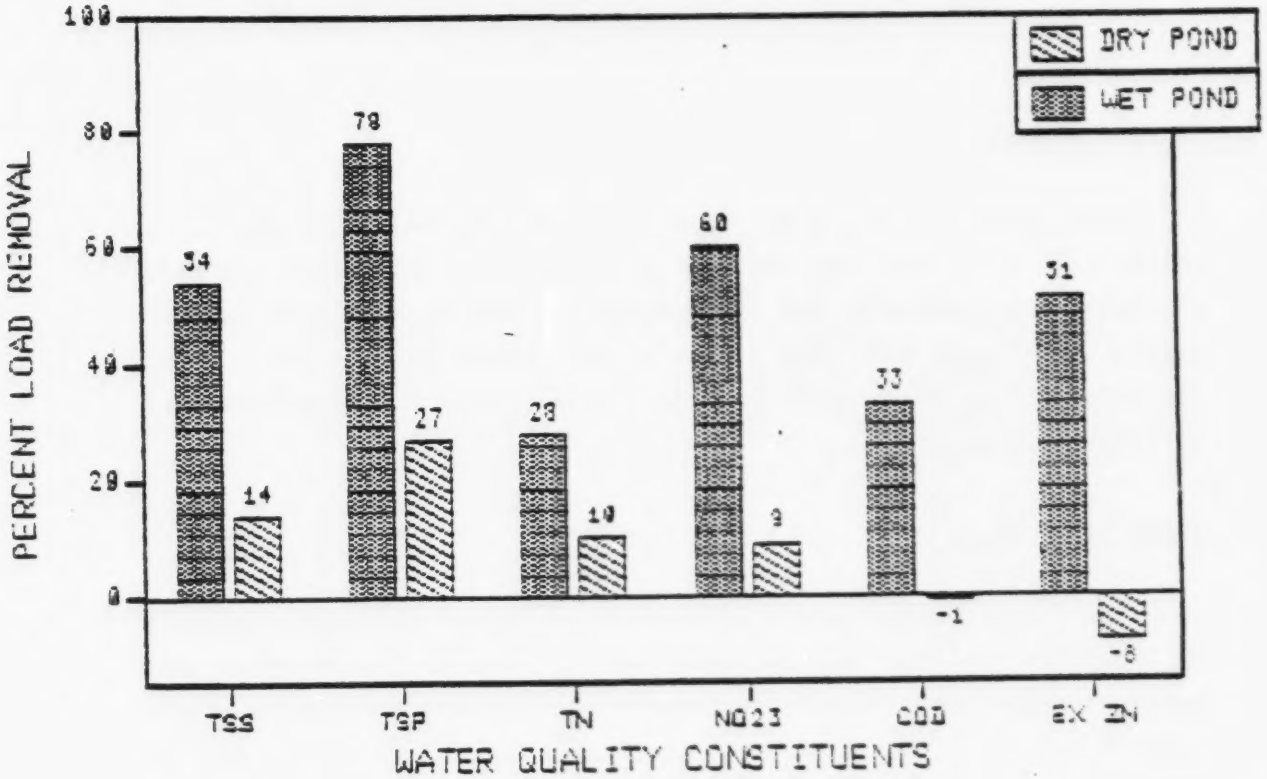
These dry pond detention structures may have some utility as peak shaving devices, but their ability to remove sediment and other pollutants is negligible. This fact is well demonstrated in Figure 5.1 which shows a comparison of pollutant removal efficiencies for wet and dry ponds. The relatively poor performance of dry ponds in removing sediment (TSS) and other pollutants is a result of several factors. These include a brief residence time, reliance on physical settling, resuspension of materials deposited in previous storms, and scour of the pond bed. It should be noted that the inclusion of a stabilized flow pathway leading into and through the pond, and extensive vegetative cover on the pond bed, would act to reduce scour of the pond bed.

Extended Detention Ponds

These facilities are essentially peak shaving devices that have been modified to provide extended detention. The principal design modification is the introduction of an outflow control that detains stormwater in the pond for an extra twelve hours. It was determined during an anlysis of sediment settling characteristics and subsequent

FIGURE 5.1

COMPARATIVE PERFORMANCE OF WET AND DRY
STORMWATER MANAGEMENT PONDS
IN THE WASHINGTON AREA NURP PROJECT



comparison with field data that most of the settling occurs within the first twelve hours following a runoff event. Under this arrangement an extended detention pond modified to detain water for twelve hours can serve as a moderately effective BMP. As a rule, high removal efficiencies are achieved for particulates due to settling, but the removal of soluble nutrients is minimal in the absence of biological processes. The overall performance of the extended detention pond monitored and evaluated during NURP was not as good as wet ponds, but was substantially better than regular detention ponds. Additional information on the design of extended detention ponds can be found in a previous report on nonpoint pollution management strategies (NVPDC, 1980).

Porous Pavement

This practice achieved high pollutant removal efficiencies in excess of 60 percent for sediment and all of the pollutants studied. A direct comparison with the efficiencies of infiltration pits is presented in Figure 5.2. The use of porous pavement is well suited for the control of urban runoff from parking lots or other broad expanses of impervious cover.

Infiltration Pits

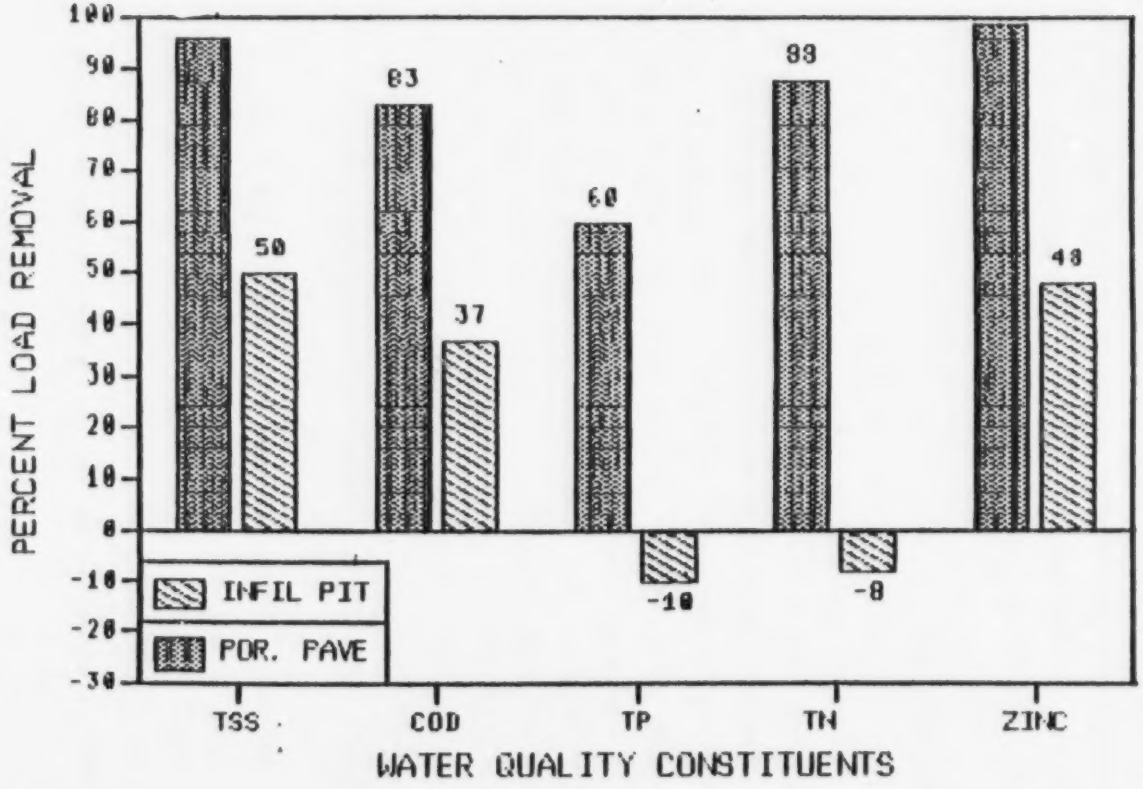
The infiltration pits studied in NURP showed respectable removal efficiencies in the neighborhood of 50 percent for sediment and several other pollutants. However, median efficiencies for the removal of total nitrogen and total phosphorus were either zero or negative. While it does not appear that the specific structures studied provided any nutrient removal, it would be possible to design infiltration pits that achieved higher nutrient reductions.

Grassed Swales

In the NURP analysis, the grassed swales sites demonstrated very little value in pollutant removal. By and large they produced no significant improvement in runoff quality over curb and gutter systems.

FIGURE 5.2

Comparative Pollutant Removal Performance Porous Pavement and Infiltration Pits



However, there are some net benefits associated with their use. They tend to reduce impervious cover which acts to reduce the generation of stormwater. And the runoff from small rainfall events is often infiltrated within the swales to the extent that no runoff whatsoever is delivered to streams during small storms. It should be noted that their use in combination with other practices would probably be very beneficial. It should be further noted that their effectiveness in reducing stormwater runoff and nonpoint pollution may be enhanced in sandy loam soils like those common in Prince George's County.

Other Measures

Several other practices that are non-structural in nature are very effective in reducing the nonpoint loads, erosion, sedimentation, and habitat impairment that is typically the result of development in urbanizing watersheds. Foremost among these are imaginative land use planning that is sensitive to areas of potential environmental hazard (soils, slopes, etc.), the encouragement of cluster development and buffer zones, the preservation of open space, and recognition of the importance of protecting stream valleys themselves. Adherence to these planning practices tends to hold down the growth of impervious cover and to reduce the ease with which stormwater and pollutants are conveyed to streams. These practices also tend to minimize the direct impacts of development upon the stream habitat.

Another practice that can provide net benefits to water quality and instream habitat is the preservation of agricultural land. However, this must be accompanied with the implementation of agricultural BMPs in order for benefits to accrue as agricultural land in an uncontrolled condition represents a serious source of pollutants and sediment.

SUMMARY OF MANAGEMENT PRACTICES

Several of the key points discussed in this Chapter were as follows:

- Flood control practices that would generally not provide much erosion and water quality control are currently under consideration by the county.

- As an example of an application of BMPs, it was projected that the widespread application of wet ponds coincident with development would be effective in reducing nutrient and sediment loads and streambank erosion.

- The cost of wet ponds as an example of a basinwide management strategy was estimated to enable preliminary comparisons with the costs of lever construction, flood proofing, land aquisition, and the construction of large single purpose flood control alternatives as now being considered by the Stormwater Management Technical Committee.

- It was suggested that wet ponds can provide the required flood control protection as well as erosion and water quality benefits for a modest increase in cost. According to a recent resident attitude survey, wet ponds are generally perceived as attractive resources in terms of increased real estate value, aesthetic appeal, recreational opportunities, and wildlife attraction.

- The effectiveness and suitability of a full range of BMPs including extended detention ponds, swale draiange, porous pavement and imaginative land use planning was presented.

- Although not specifically addressed in this analysis, nonpoint source practices would be valuable in limiting the amount of bacteria and trace metals delivered to Piscataway Creek and its tributaries since these pollutants are for the most part transported to streams in stormwater.

CHAPTER 6. RECOMMENDED MANAGEMENT PLAN

"Planned" land use information provided by M-NCPPC calls for residential and commercial development within the Piscataway watershed to grow from its current status of occupying approximately 20 percent of the watershed to nearly full coverage of greater than 90 percent. Although no specific time frame for this development is given, and presumably it might happen slowly over several decades, planning at this point in time for it to occur is nevertheless very worthwhile. Sediment loads, streambank erosion and scour were all projected with the watershed model to more than double. Since Piscataway Creek currently shows evidence of serious sedimentation, turbidity and streambank erosion problems, the already stressed existing situation could be further aggravated. Increased average annual nutrient loads were also projected, and this is of concern principally because of eutrophication problems in the Piscataway embayment and Potomac estuary. In order to provide some protection for Piscataway Creek, and, to a lesser extent, the Upper Potomac estuary, the following measures are recommended.

RECOMMENDED MANAGEMENT PRACTICES

- The flood control alternatives under consideration by the Stormwater Management Technical Committee would probably have a negligible impact on reducing nonpoint source pollutant loads and the generation of sediment within the watershed. Inclusion in the Comprehensive Master Plan for the watershed of specific measures aimed at protecting water quality and aquatic life is recommended.

- Increases in stormwater volume and associated sediment loads pose the biggest threat to water quality in the watershed. Every effort should be made to put controls in place that would maintain runoff volume and flow rates at predevelopment levels.

- A large degree of control over the increases in loads projected under the "planned" land use situation would be possible with the widespread application of Best Management Practices.

- Management practices such as the use of wet ponds, extended detention dry ponds, porous pavement, or other well-designed infiltration controls could be implemented to provide flood control as well as erosion and water quality benefits.

- In the selection of controls for specific sites it should be remembered that the use of measures that provide a high level of nutrient removal will benefit eutrophication abatement in the Piscataway embayment and the Upper Potomac estuary.

- The Piscataway Watershed contains extensive areas of forest and wetlands that represent a valuable wildlife resource. Adequate protection of this threatened resource should be a priority.

REFERENCES

Anderson-Nichols, Inc., "Guide to the Application of the Hydrological Simulation Program - Fortran (HSPF)", Preliminary review draft, Palo Alto, CA, 1982.

Ecological Analysts, "Baseline Inventory of Wetlands in Piscataway Creek and the Adjacent Potomac River", Report prepared for WSSC, Towson, MD, 1978.

Hartigan, J.P., Quasebarth, T.F. and Southerland, E. (1982). "Use of Continuous Simulation Model Calibration Techniques to Develop Nonpoint Pollution Loading Factors", Proceedings of Stormwater Water Quality Model Users Group Meeting, U.S. Environmental Protection Agency, Environmental Research Laboratory, Athens, Georgia, March 25-26, 1982.

Hydrocomp, Inc., "Users Manual for Hydrologic Simulation Program - Fortran (HSPF)," EPA-600/9-80-015, U.S. EPA, Athens, GA, April 1980.

Maryland Department of Natural Resources, "Survey of Anadramous Fish Spawning Areas in the Potomac River and Upper Chesapeake Bay Drainage", Annapolis, MD, 1975.

Maryland Department of State Planning, "Areas of Critical State Concern", Baltimore, MD, January, 1981.

Metropolitan Washington Council of Governments, "An Initial Assessment of Nonpoint Source Loads in the Piscataway Creek Watershed", Washington, D.C., November 1981.

Metropolitan Washington Council of Governments, "The Piscataway Watershed Model: Documentation of the Hydrologic Calibration and Verification", Washington, D.C., April 1982.

Metropolitan Washington Council of Governments, "Water Quality in Piscataway Creek: A Technical Assessment," Washington, D.C., April 1983.

Metropolitan Washington Council of Governments, "An Evaluation of the Costs of Stormwater Management Pond Construction and Maintenance," Washington, D.C., June, 1983.

Metropolitan Washington Council of Governments, "Final Report on Nationwide Urban Runoff Program," Washington, D.C., in preparation, 1983.

National Weather Service, "Metropolitan Climatological Summaries - National Capital Area," NOAA, NWS, Silver Spring, Md., 1980-1981.

Northern Virginia Planning District Commission and Virginia Polytechnic Institute and State University, "Occoquan/Four Mile Run Nonpoint Source Correlation Study", report prepared for the Metropolitan Washington Council of Governments, Water Resources Planning Board, Washington, D.C., 1978.

Northern Virginia Planning District Commission, "Input Parameters for NPS Model Loading Files," report prepared for Metropolitan Washington Council of Governments, Falls Church, Va., 1979.

Northern Virginia Planning District Commission, "Guidebook for Screening Urban Nonpoint Pollution Management Strategies", Report prepared for Metropolitan Washington Council of Governments, Falls Church, Va., 1980.

Prince George's County, "Technical Data Base Study - Piscataway Creek Watershed", Stormwater Management Technical Committee, Upper Marlboro, MD, 1981.

Prince George's County, "Draft Management Plan for Piscataway Creek", Stormwater Management Technical Committee, Upper Marlboro, Md., 1982.

Schueler, T. R. and Sullivan, M. P., "Management of Stormwater and Water Quality in an Urbanizing Watershed", Tenth International Symposium on Urban Hydrology, Hydraulics and Sediment Control, University of Kentucky, Lexington, KY, July, 1983.

Thurston, R.V., et.al., editors, "A Review of the EPA Redbook: Quality Criteria for Water", American Fisheries Society, Bethesda, Md., 1979.

Urban Wildlife Institue, "Urban Wetlands for Stormwater Control and Wildlife Enhancement: Analysis and Evaluation," Columbia, Md., 1983.

Smithsonian Institute, "Natural Areas of the Chesapeake Bay Region", Washington, D.C., 1974.

Soil Conservation Survey, "Preliminary Investigation of the Piscataway Creek Watershed", USDA, SCS, College Park, MD, 1978.

APPENDIX A

PISCATAWAY LAND USES IN ACRES BY CATEGORY - EXISTING

Subwatersheds	111	112	113	114	115	12	13	14	15	16	21	22	(41+42)	191	192	Total Area	Impervious Area
#1	98			12			1740		43		6	23	236	60	139	2357	1326
#2	45	157		22			5				12	76	291	12	245	865	77
#3	22	17										47	385	17	6	494	15
#4		6		126							45	96	265	86	33	657	63
#5	10	76	160	151			4				174	65	942	318	118	2018	168
#6	23	99		17					11		63	309	669	127	221	1539	74
#7	14	20					30		10		153	110	855	452	243	1887	83
#8	113	109	99	191			18		55		124	95	1438	348	322	2912	255
#9	18	133		11		4	12		22		101	50	816	324	119	1610	104
#10	77		276	259			12		69		448	270	1627	428	36	3502	319
#11	18			52			6				73	39	820	115	30	1153	43
#12	6		51								393	36	1080	250	85	1901	51
#13	193								10		200	144	2088	268	64	2967	89
#14	8	24	106		16		5				102	146	829	128	16	1380	39
TOTAL	645	641	692	841	16	4	1632		220		1894	1506	12,341	2933	1677	25,242	2706

APPENDIX A

PISCATAWAY CREEK LAND USE IN ACRES BY CATEGORY - PLANNED LAND USE

Subwatersheds	111	112	113	114	115	(12 + 13)	14	15	16	(21 + 22)	(41 + 42)	(191 + 192)	Total Area	Impervious Area
#1	5	218				1868		37			60	165	2353	1445
#2	40	468		7		332					19		866	368
#3	64	362				17						53	496	121
#4	277	246		136		5						6	670	175
#5	420	1224	160	207								27	2038	516
#6	537	755		17				12			13	204	1539	323
#7	913	935				23		6				12	1889	439
#8	920	1188	169	532		33		49					2891	797
#9	1226	313		11		27		22				29	1628	370
#10	802	719	636	671		121		62			13	471	3495	968
#11	882	39	45	52		6						124	1148	231
#12	1678	92	51									83	1904	377
#13	2901	5						10		6	40	10	2972	593
#14	951	280	106		16	5						37	1395	309
TOTAL	11,616	6,844	1,167	1,633	16	2,437		198		6	145	1,221	25,283	7,032